NOAA Hazardous Weather Testbed Experimental Forecast Program

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# Researchers: "Why collaborate with Forecasters?"

- Forecasters are the end-users of our research efforts – if we operated in the business world, we would survey our customers to see how we could serve them better (e.g., make better models).

- Many forecasters have exceptional insight and are highly motivated; they thoroughly (and critically!) examine forecasting tools (e.g., NWP models) every day and have a very different perspective compared to a developer or researcher.

Forecasters: "Why collaborate with Researchers?"

- Research Scientists are often more aware of the latest developments in theory and often have access to research tools (e.g., numerical models that are not readily available to forecasters.
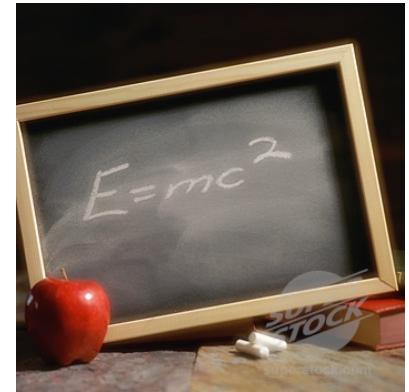

- Many Researchers have exceptional insight and are highly motivated to work on applied research problems; they develop many of the tools that forecasters use and know the strengths and weaknesses of these tools.
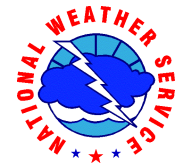
The annual Spring Forecasting Experiment (SFE)

- *The cornerstone of HWT…a 6-8 week experiment conducted each spring to evaluate emerging scientific concepts and tools in a simulated operational forecasting environment, usually attracts ~100 participants annually.*

- *Yet, the HWT is much bigger than even this!*

…Scenes from SFE2011…
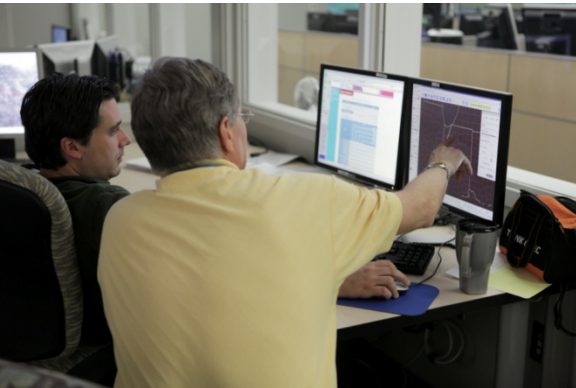
HWT Spring Experiment 2010 Participating Institutions:

NOAA Agencies

-NCEP/EMC (2)
-NCEP/AWC (6)
-NCEP/HPC (5)
-NCEP/SPC (7)
-NCEP/OPC
-NWS/ABQ
-NWS/HUN
-NWS/ANC
-NWS/CAE
-OAR/NSSL (4)
-NESDIS (2)

-NWS/RAH
-NWS/ILN
-NWS/OKX
-NWS/RLX
-NWS/ATCSCC
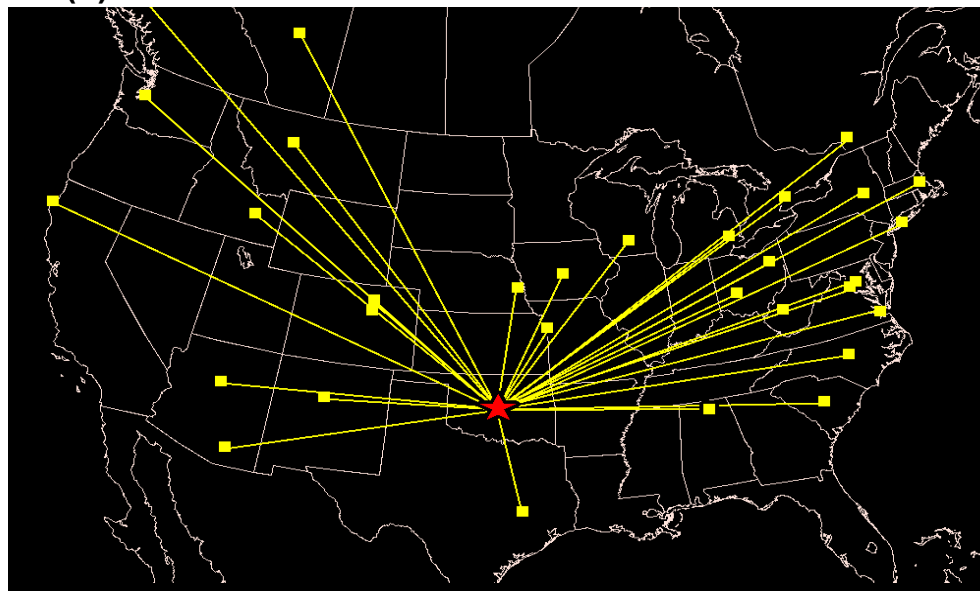-NWS/OST (5)
-NWS/MDL (2)
-CIRA/CSU (2)
-OAR/GSD (3)

-NWS/DTX
-NWS/EAX
-NWS/EKA
-NWS/TWC
-NWS/FGZ
-NWS/PIH
-NWS/TFX
-CIMSS/UW(8)
-OAR/PSD

Universities

-Oklahoma
-Iowa State
-Albany/SUNY (3)
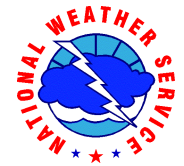-Texas A&M
-MIT/LL
-UA-Huntsville (2)

Gov't Agencies

-NCAR/DTC (6)
-FAA/Academy (2)
-FAA/ATCSCC (2)
-NASA/SPoRT (4)
-AFWA (2)
Environ. Canada (3)

Private

-Mitre (CAASD)
-FirstEnergy
-SSAI

-

The HWT is a facilitator of R2O & O2R collaboration across the larger community

NOAA Hazardous Weather Testbed

Supports and promotes collaborative research activities between SPC, NSSL, WFO OUN, and the broader meteorological community of research scientists, academia, and forecasters to accelerate the transition of promising new severe weather forecasting and warning techniques into operations.

Three Main Program Areas…

Experimental **F**orecast **P**rogram

EFP

EWP

Experimental **W**arning **P**rogram

*Prediction of hazardous weather events from **a few hours to a week in advance***

*Detection and prediction of hazardous weather events **up to several hours in advance***

Leads: Jack Kain & Steve Weiss
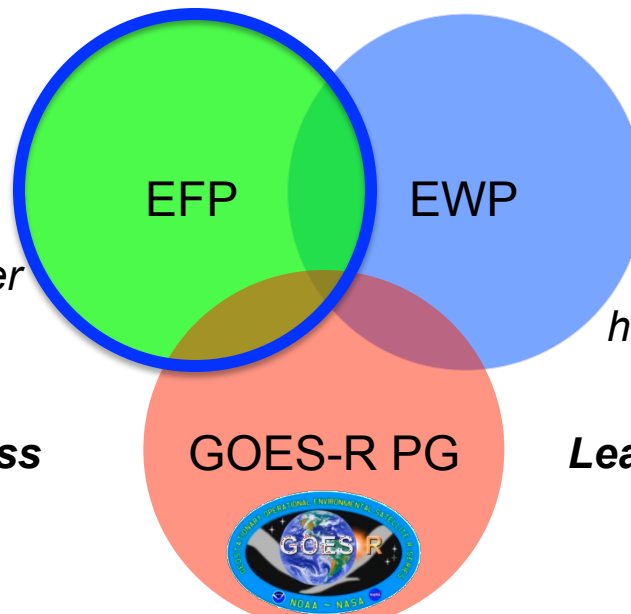
GOES-R PG

Leads: Travis Smith & Dave Andra

GOES-R Proving **G**round

Tangible Operational Impacts

15 Nov 2005 tornado outbreak

Isolated cells ahead of the main line

Tornadic Supercells

WRF-NMM Simulated 1 km Reflectivity

Observed Base Reflectivity
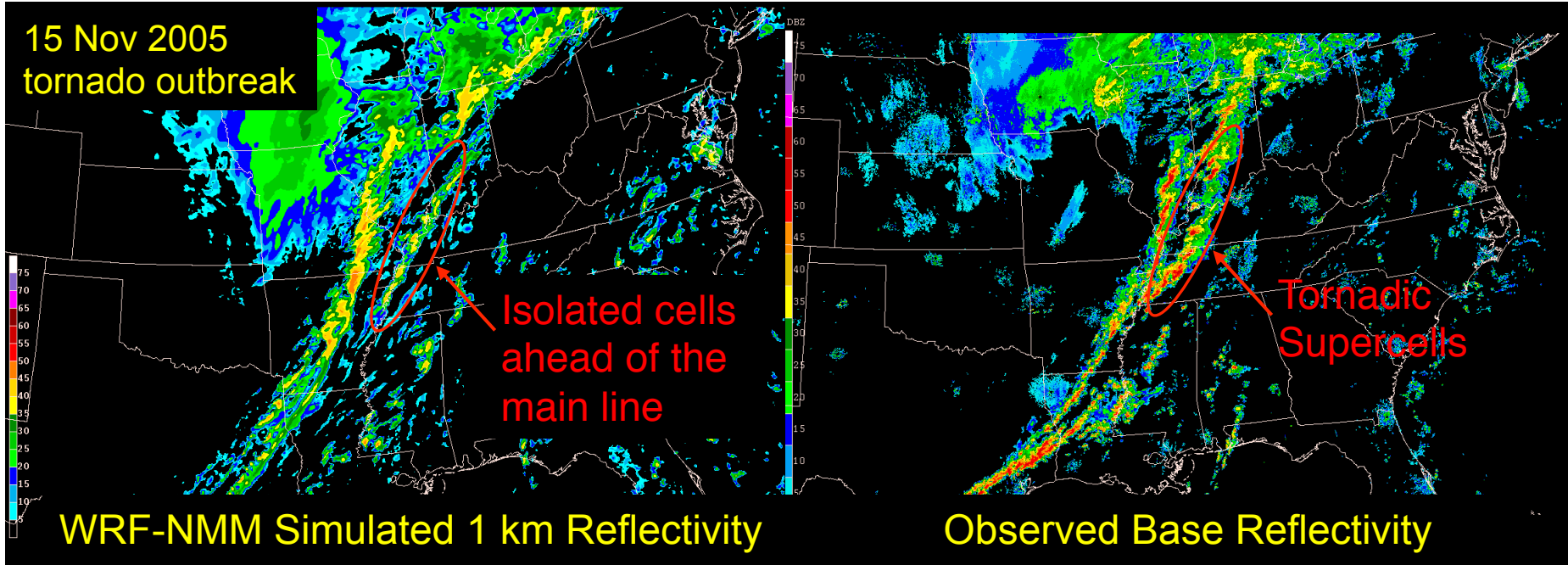
"The WRF-NMM4 provided very useful input regarding the mesoscale organization and character of storms…I used it to help delineate where/when watches would be required."

John Hart - SPC Day Shift Lead Forecaster

EFP Science and Forecasting Objectives

1. *Use a simulated operational forecasting environment as a framework for exploring the utility of high-resolution Convection-Allowing Models (<u>CAMs)</u> and ensembles as guidance for forecasts of hazardous convective weather.*

2. *Develop, refine, and test <u>data mining tools </u>for automated detection of processes/features in high-resolution model forecasts that are strongly correlated with hazardous convective weather and develop reliable probabilistic forecast guidance based on their statistical properties.*

3. *Explore the initialization and short-term forecast performance of deterministic CAMs using different <u>data assimilation schemes.</u>*

4. *Develop and test techniques for combining human forecasts and statistical attributes of forecast ensembles to optimize forecast skill [SPC priority].*

5. *Develop and explore new ways to <u>visualize </u>high-resolution model output.*

HWT SFE 2011 Objectives

- **Spring Forecasting Experiment 2011: May 9 – June 10 (5 Weeks)**

  - **Severe Thunderstorm Component (SPC/NSSL)**
    - Continuation of ongoing test and evaluation of CAM and SSEF guidance for severe storm prediction
    - Testing of guidance for higher temporal resolution (3-hr periods)

  - **Convective Initiation (CI) Component (NSSL/SPC/GSD)**
    - Explore different definitions for
      1. Convective Activity CA (based on lightning, updraft strength, reflectivity)
      2. CI (CA grid points characterized by "new" convective development)
    - Establish a baseline skill for current convection-allowing models
    - Explore new diagnostic tools to help us understand the CI process in CAMs

  - **QPF/Heavy Rain Component (HPC/NSSL/SPC)**
    - Explore the utility of CAMs for QPF
    - Bias corrected SREF and SSEF and other new guidance
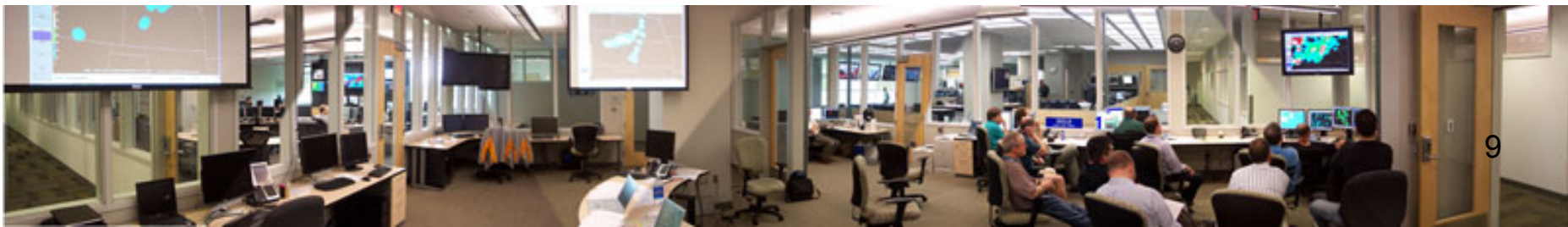
HWT-EFP 2011
High Resolution Modeling Systems

- EMC
  - HiResWindow Near-CONUS 4 km WRF-NMM (48h)
  - HiResWindow Near-CONUS 5.1 km WRF-ARW (48h)
  - NAM-NMMB CONUS 4 km Nest (60h)
- NSSL
  - CONUS 4 km WRF-ARW (36h)
- CAPS
  - CONUS 50 member 4 km Ensemble (36h)
    - Focus on core 25 members with mixed IC-physics perturbations
    - Test smaller memberships (5, 15, 25) in comparison to full SSEF
    - Physics sensitivity testing (microphysics, PBL)
    - Data assimilation testing (cycled, non-cycled, no DA)
- GSD
  - CONUS Hourly 3 km HRRR (15h)
- NCAR
  - Two-Thirds CONUS 3 km WRF-ARW (48h)

WRF-NMM Simulated Reflectivity
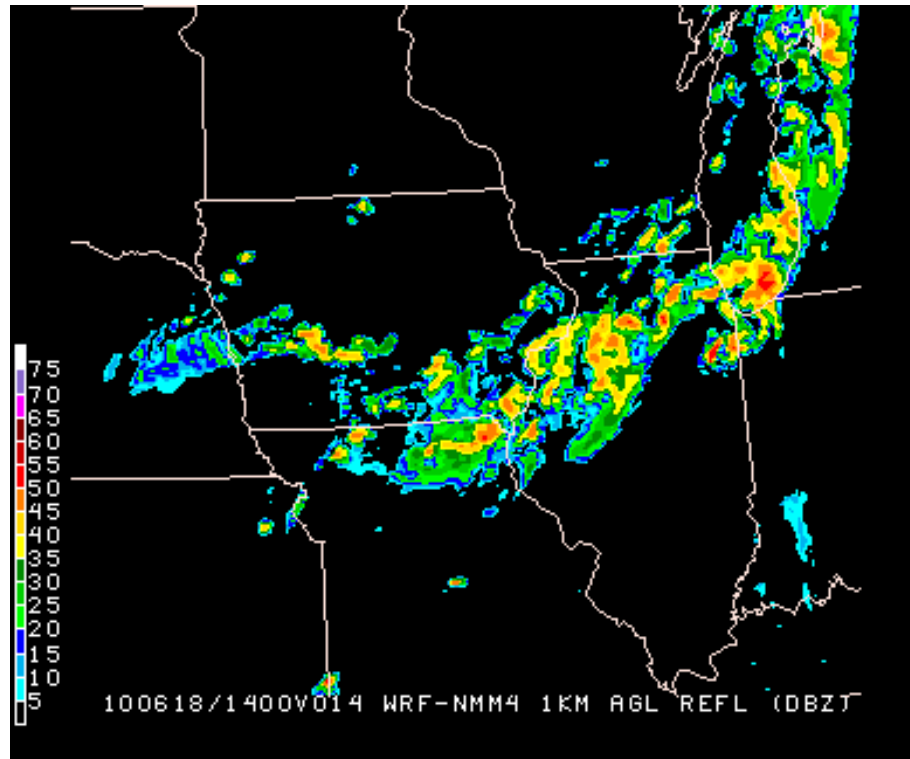
SSEF Prob. Matched 6-hr QPF
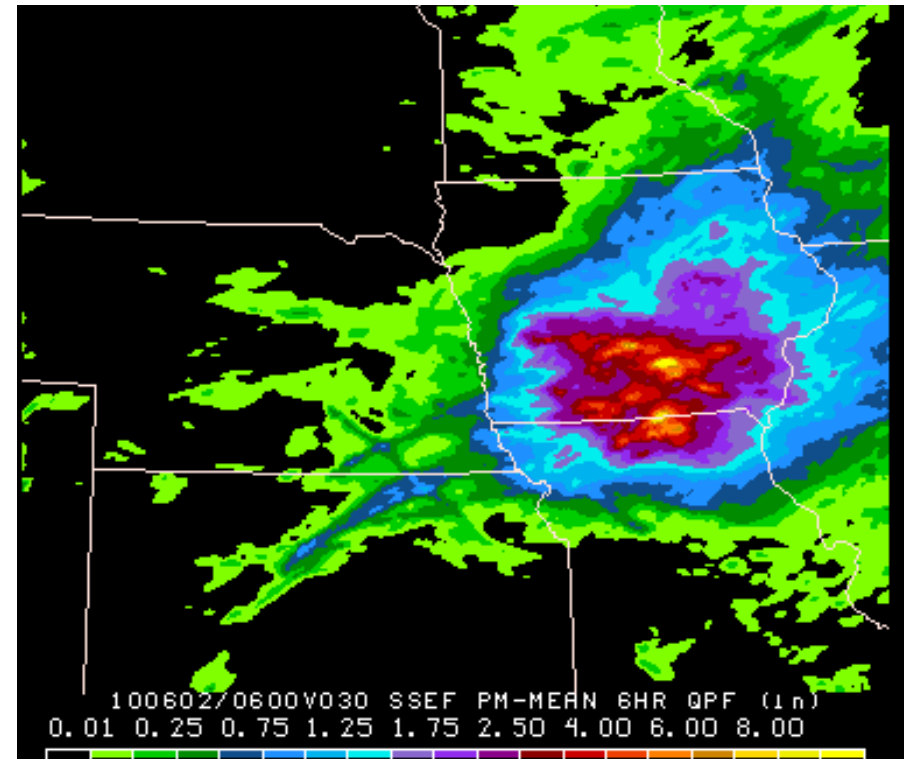
A technique called "probability matching" was utilized as an alternative to the traditional ensemble mean for fields such as precipitation and simulated reflectivity. Probability matching basically involves replacing the ensemble- mean distribution with a distribution sampled from the individual ensemble members and thus helps retain the amplitude of individual members.

WRF Models Hourly Maximum Fields

- Provides simulated storm attribute information
  - Track maximum value at every model time step and output each hour as **hourly maximum field** (HMF).

- HMFs include:
  - *Updraft Helicity -* represents a rotating updraft in a simulated storm (supercell)
  - *Updraft/Downdraft Speeds -* measures of convective overturning
  - *10-m AGL Wind Speed -* identifies convective gusts
  - *1-km AGL Simulated Reflectivity*
  - *Vertically Integrated Graupel -* proxy for hail in a model storm

Example Hourly Maximum Fields

Updraft Helicity (m^2s^{-2})
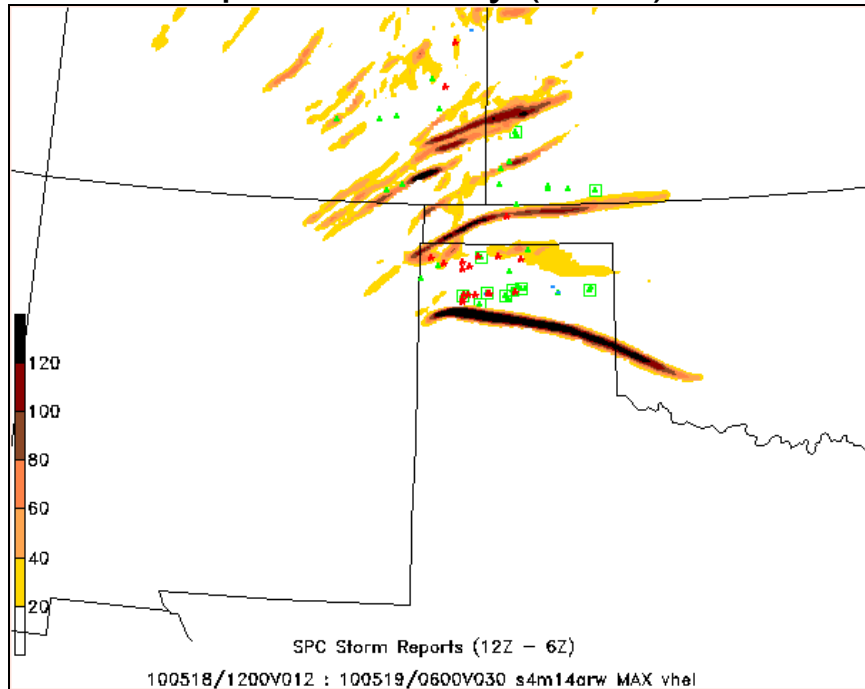
Simulated Reflectivity $\geq$ 40 dBZ
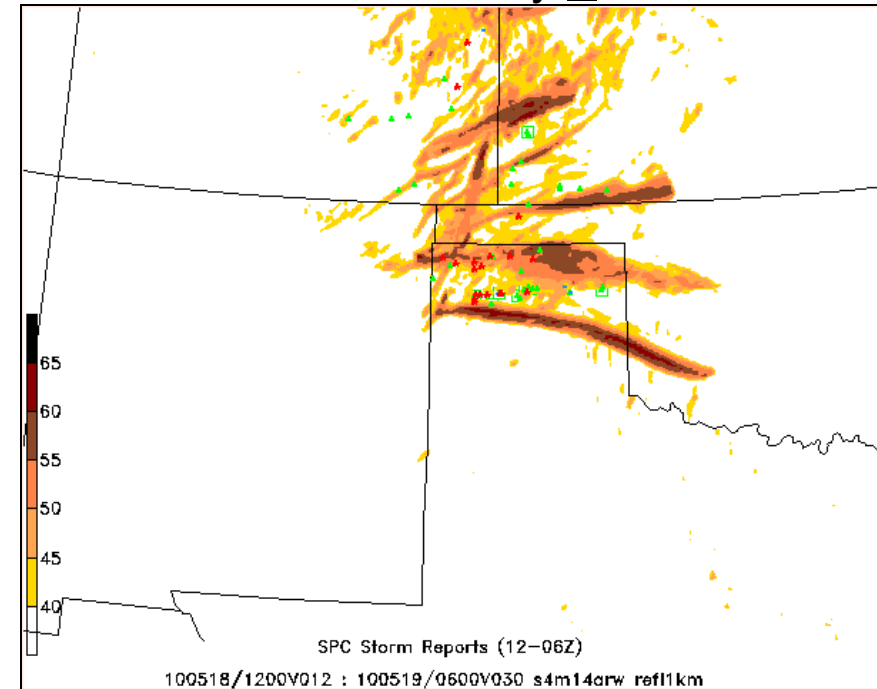
- HMFs can provide unique perspective on convective mode and simulated storm tracks.

- Co-located swaths of hourly max UH and simulated reflectivity highlight simulated long-track supercells.

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Microphysics Sensitivity

Composite frequencies of observed rainfall >0.50-in. relative to grid-points forecasting rainfall >0.50-in. at forecast hr 30 from selected SSEF members during SE2010. The boldface dot is centered on the forecasts.

For the non-Thompson schemes, the observed precipitation is northwest of the forecasts, indicating these members predicted cold pools that were too strong.

Often, the Thompson run was the outlier among the four members, generating much more extensive regions of stratiform reflectivity and spurious convection.
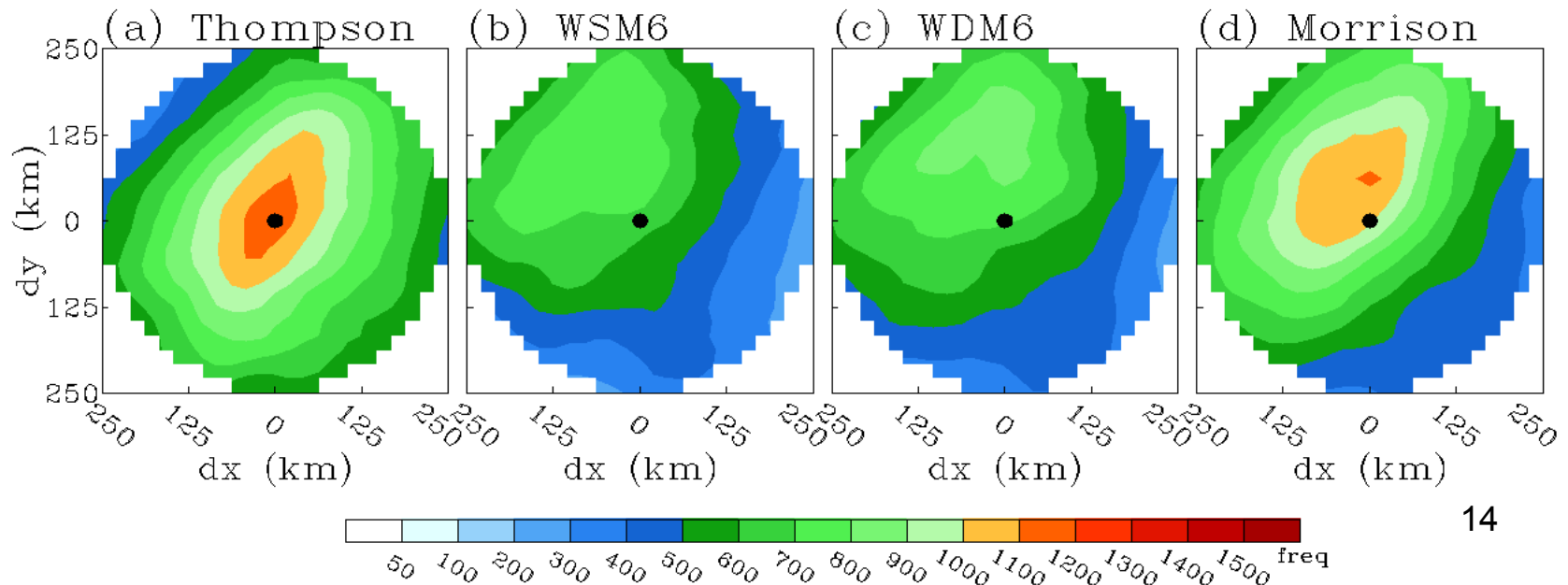
Data Assimilation Sensitivity

- Examination of different data assimilation methods and associated model short-term forecasts
  - CAPS 4 km control run with 3D-VAR DA
  - CAPS 4 km control run without DA (cold start)
  - HRRR 3 km forecast with DDFI
- Assess utility of DA/models to provide useful convective-scale forecasts in 0-6 hr period (WoF)
- Explore impacts of radar and other data in CAPS DA
  - How long does radar assimilation impact the forecast?
    - Or, when does the cold start run "catch up" to DA run?

Data Assimilation Comparison
00-hr valid 00z 2 June 2010

CAPS cn
(with DA)
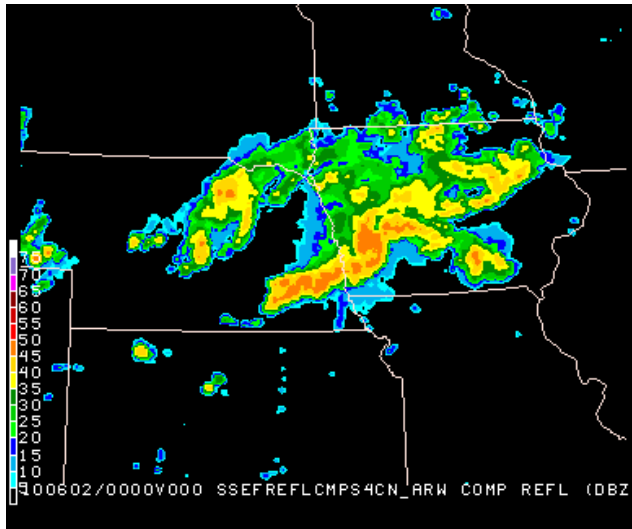
CAPS c0
(cold start)
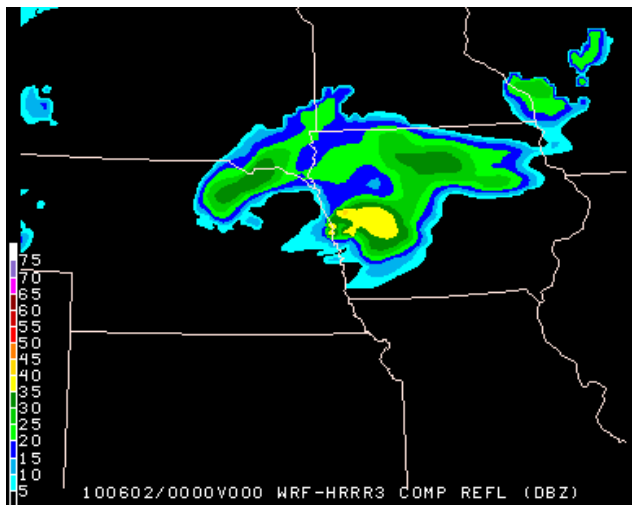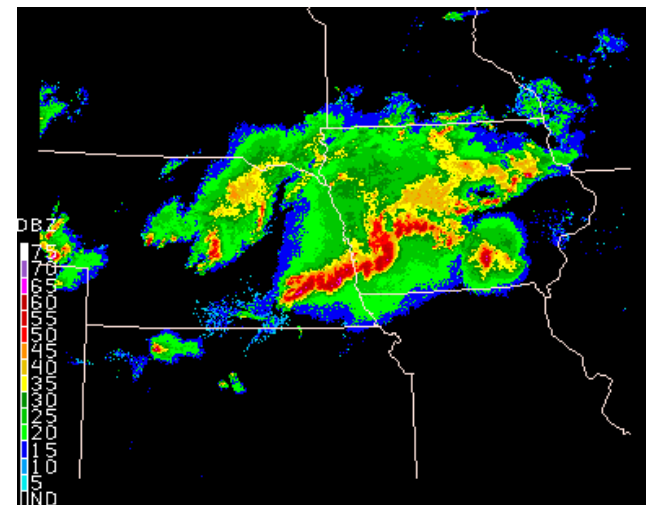
HRRR

Radar

Data Assimilation Comparison
01-hr valid 01z 2 June 2010

CAPS cn
(with DA)
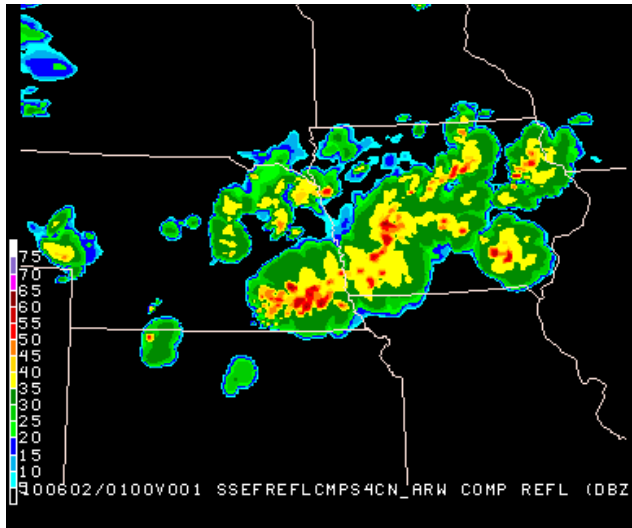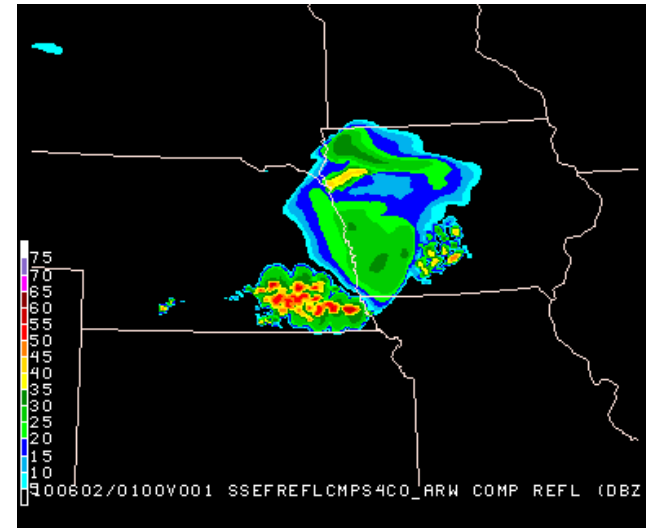
CAPS c0
(cold start)
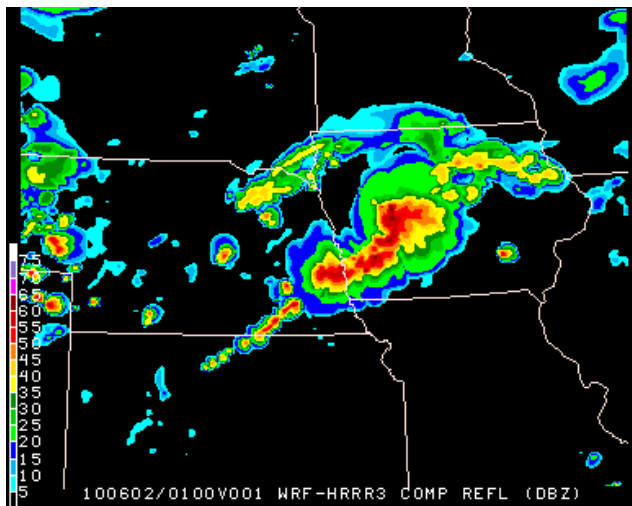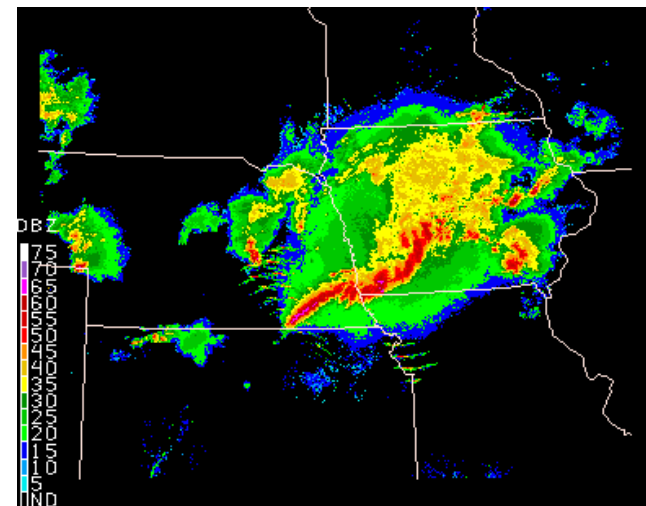
HRRR

Radar

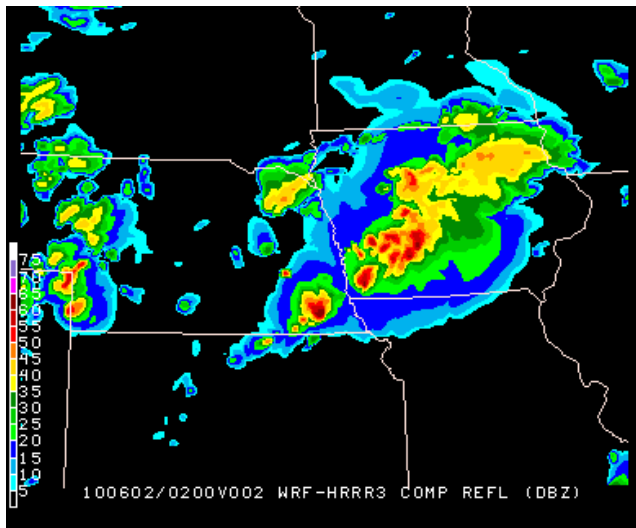# Data Assimilation Comparison
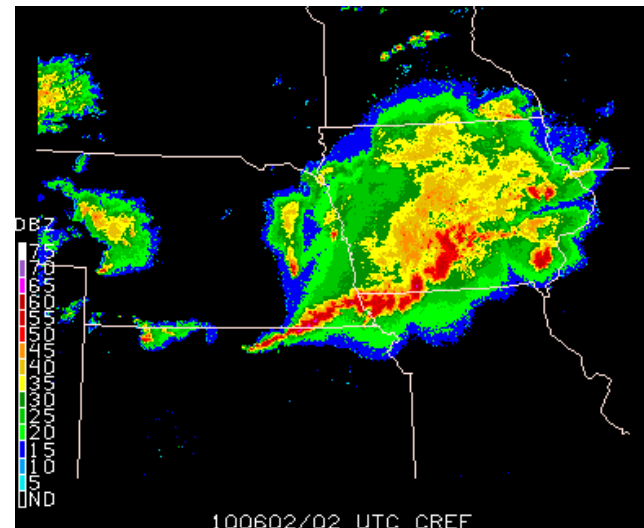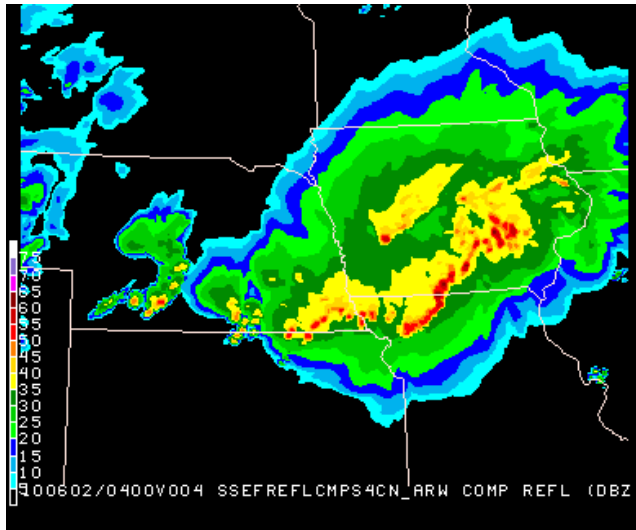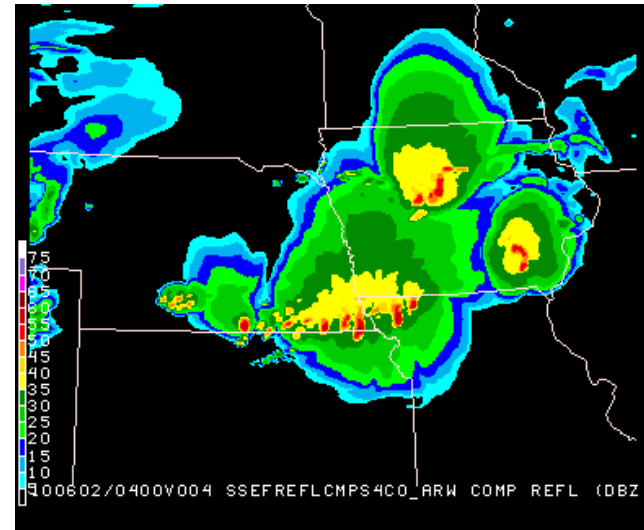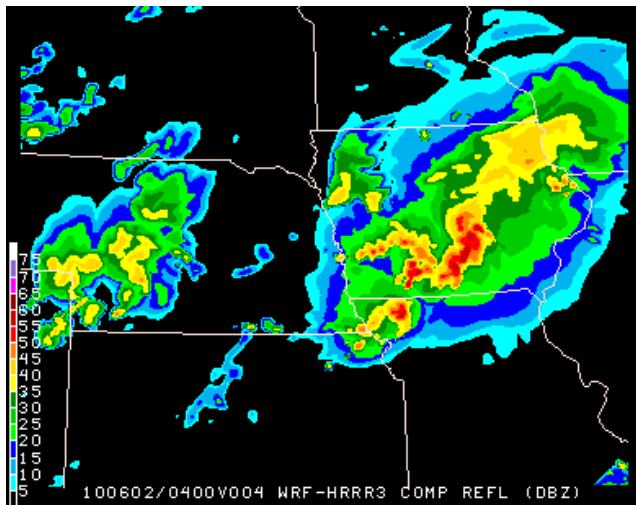## 02-hr valid 02z 2 June 2010

CAPS cn
(with DA)
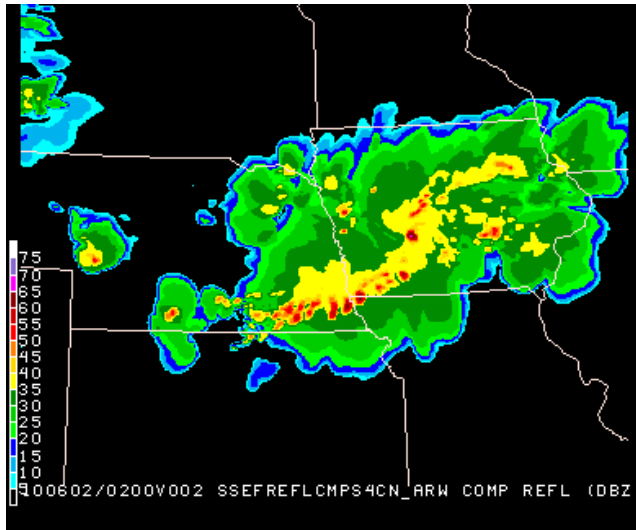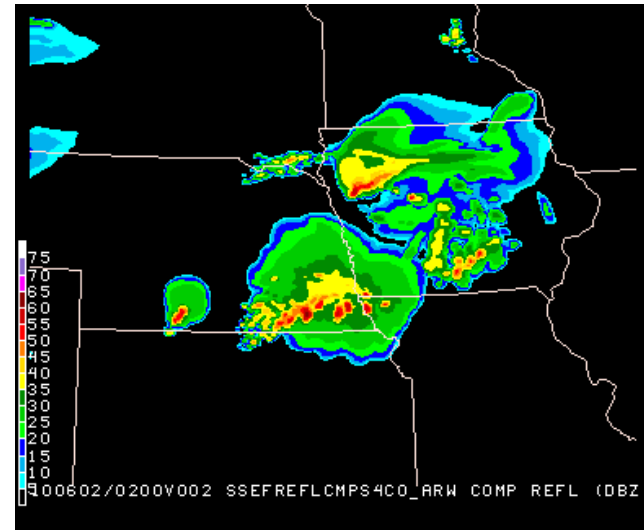
CAPS c0
(cold start)

HRRR

Radar

Data Assimilation Comparison
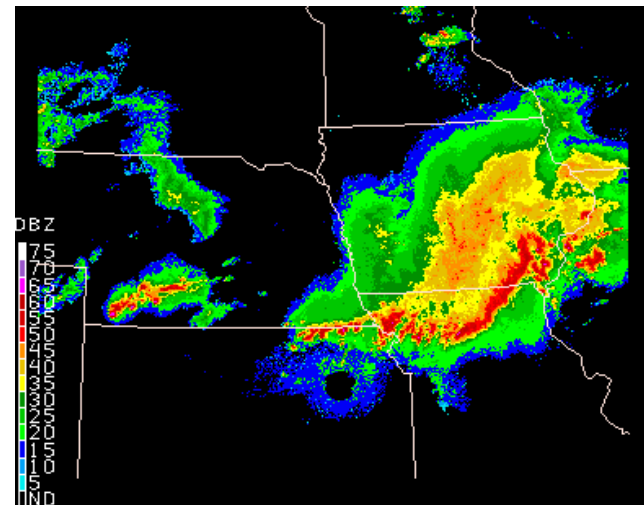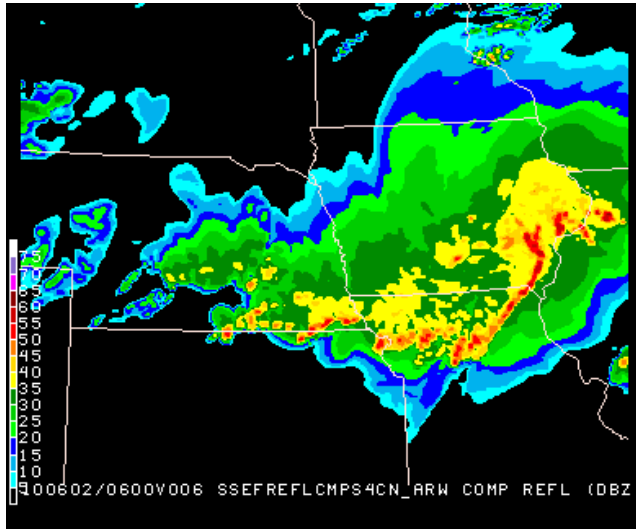## 04-hr valid 04z 2 June 2010

CAPS cn (with DA)
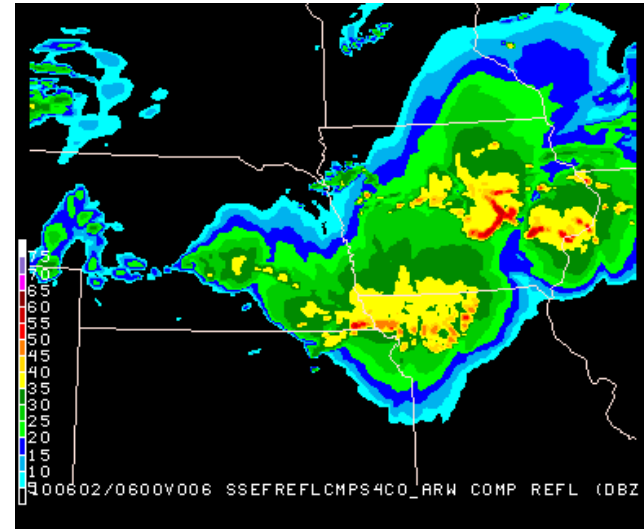
CAPS c0 (cold start)

HRRR

Radar

Data Assimilation Comparison
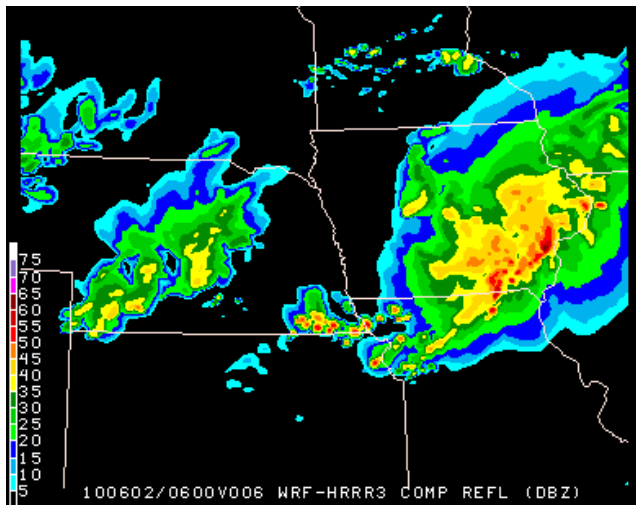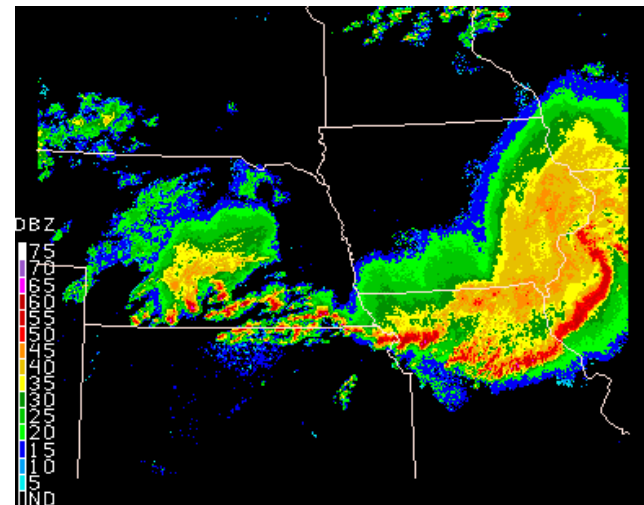## 06-hr valid 06z 2 June 2010
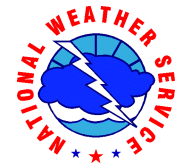

CAPS cn
(with DA)

CAPS c0
(cold start)

HRRR

Radar

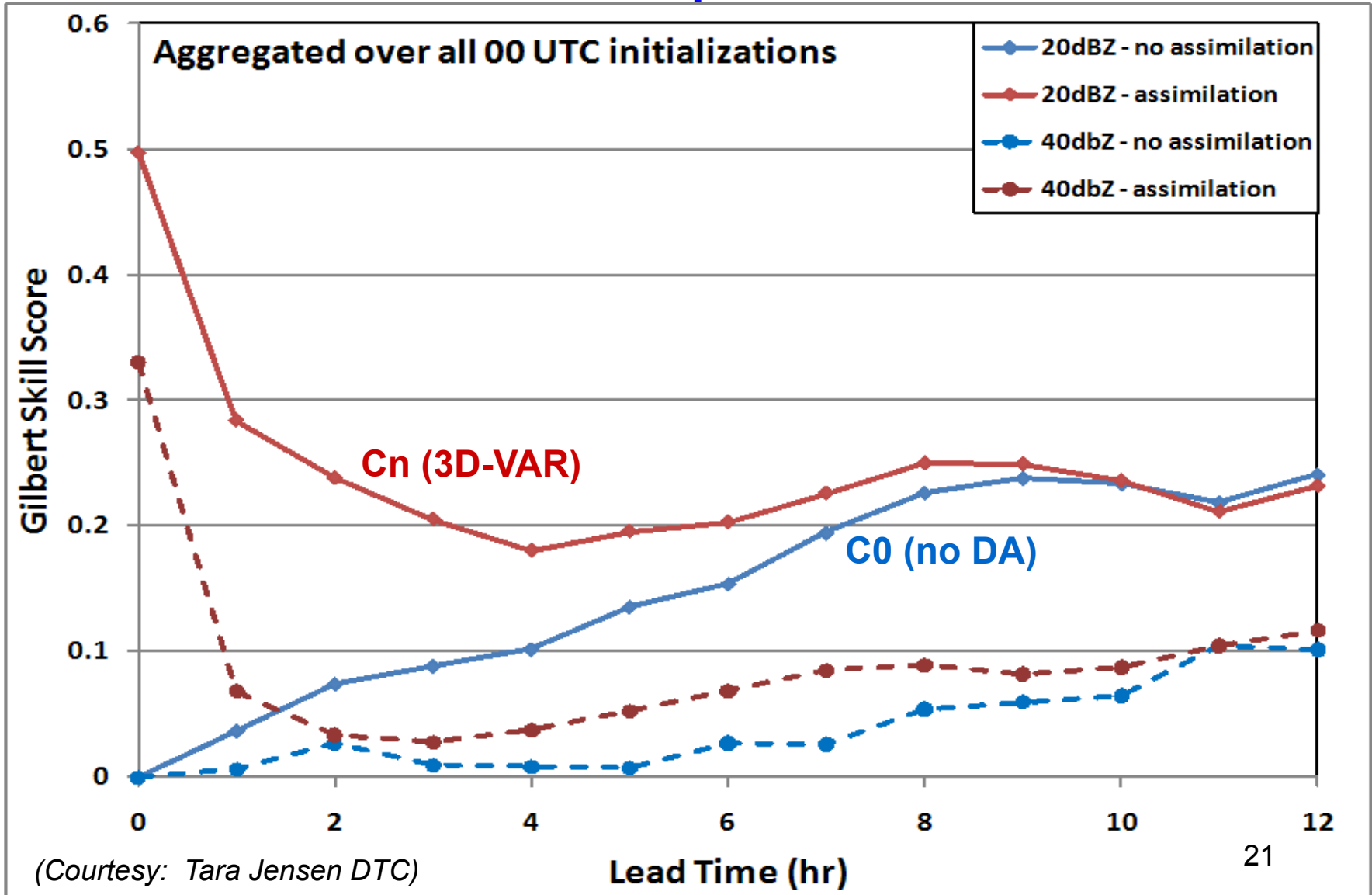# Data Assimilation: Comparison of Forecast Skill

Aggregated over all 00 UTC initializations

Legend:
- 20dBZ - no assimilation
- 20dBZ - assimilation
- 40dbZ - no assimilation
- 40dbZ - assimilation

Cn (3D-VAR)

C0 (no DA)

Gilbert Skill Score (y-axis), Lead Time (hr) (x-axis)

(Courtesy: Tara Jensen DTC)

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Convective Initiation (CI):
A new initiative for the 2011 Spring Forecasting Experiment

"Pilot Program" Objectives:

- Evaluate the utility of new objective methods for identifying and predicting CI in currently available convection-allowing models (CAMs)

- Assess the skill of CAMs for CI prediction.

- Evaluate new ways of visualizing CI forecasts, including the use of experimental workstations

Convective Initiation

NWS does not currently issue explicit forecasts for CI. In fact, there is no generally accepted definition of CI in the meteorological community. Different criteria tested to identify Convectively Active (CA) grid points:

1) Model simulated **CG lightning**: McCaul et al (2009) simulated lightning detection algorithm based on graupel content and flux, using threshold values determined by mapping NLDN data to the model framework
2) Measures of **updraft strength and precipitation content**: exceed empirically derived W, Q_r, Q_g thresholds.
3) Model **simulated reflectivity** > 35 dBz simulated reflectivity at -10 C level (to avoid bright band effects)

Comparison of identified CA from a 24-h forecast of the NSSL WRF model using the lightning, updraft strength, and reflectivity CA criteria (left), and the probability of CI SLTG using kernel density estimated spatial probability fields from this single deterministic prediction of CI (right).

Algorithms used to identify CI need additional work in SFE 2012, as they were often not consistent with subjective assessments of CI.
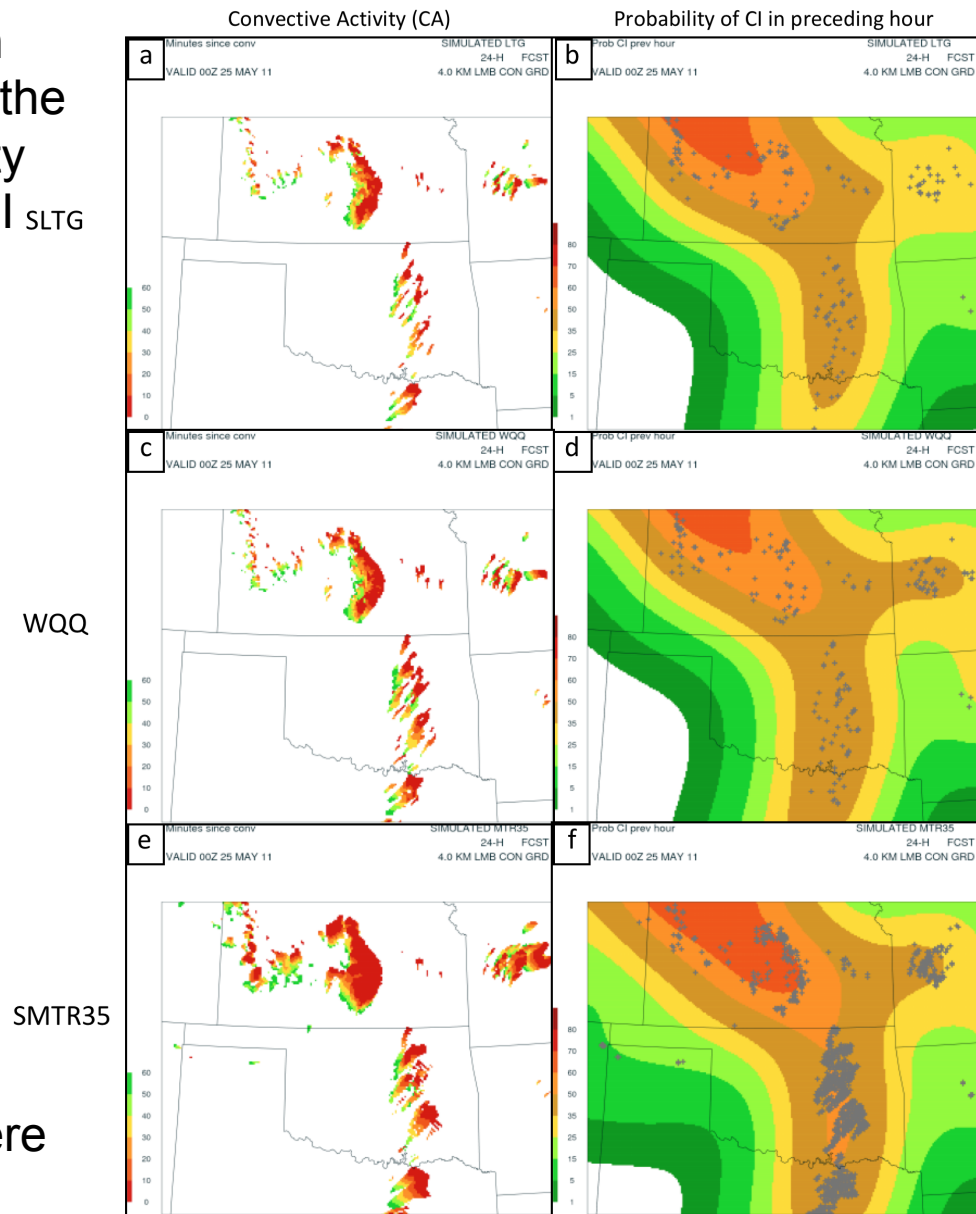

Fig. 1 Examples of raw CA field (left column) and derived 1h probabilities of CI (right column) for each of the 3 sets of CA criteria, derived from a 24 h NSSL-WRF forecast valid 00 UTC 25 May 2011. The small '+' signs on the right indicate the specific locations of CI points within the last hour, identified using the CI_1 algorithm.

Storms could be traced back to the initiation mechanism, such as horizontal convective rolls and gravity waves seen in model forecast vertical motion and water vapor fields.

A key component of understanding CI in the model is to confirm that the model correctly represents actual physical processes.
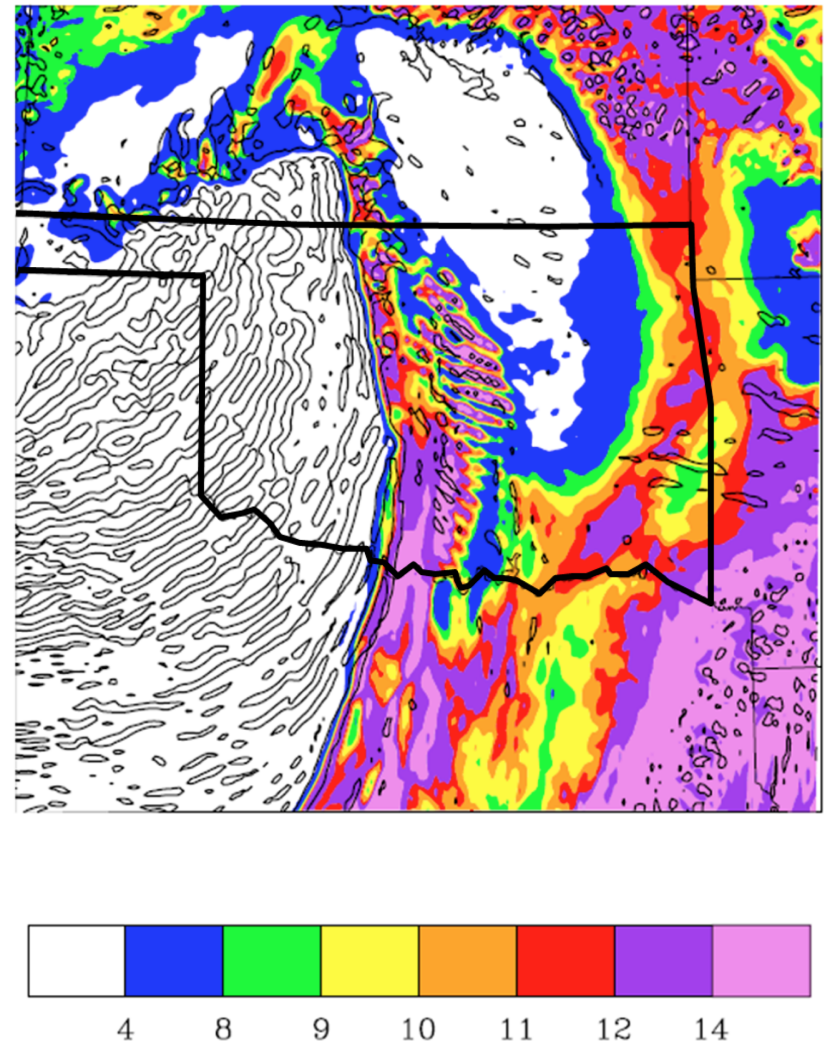

21 UTC MYJ

	4	8	9	10	11	12	14

Fig. 11. Sample diagnostic plot showing vertical velocity (contour interval 0.25 ms^{-1}) and water vapor mixing ratio (color fill, g kg^{-1}) at model level 12 (approximately 1.1 km AGL). Note the horizontal-convective-roll-like features in the drier air west of the dry line (indicated by sharp east-west moisture gradient) and the transverse rolls, apparently in stable air above the PBL, in central Oklahoma.
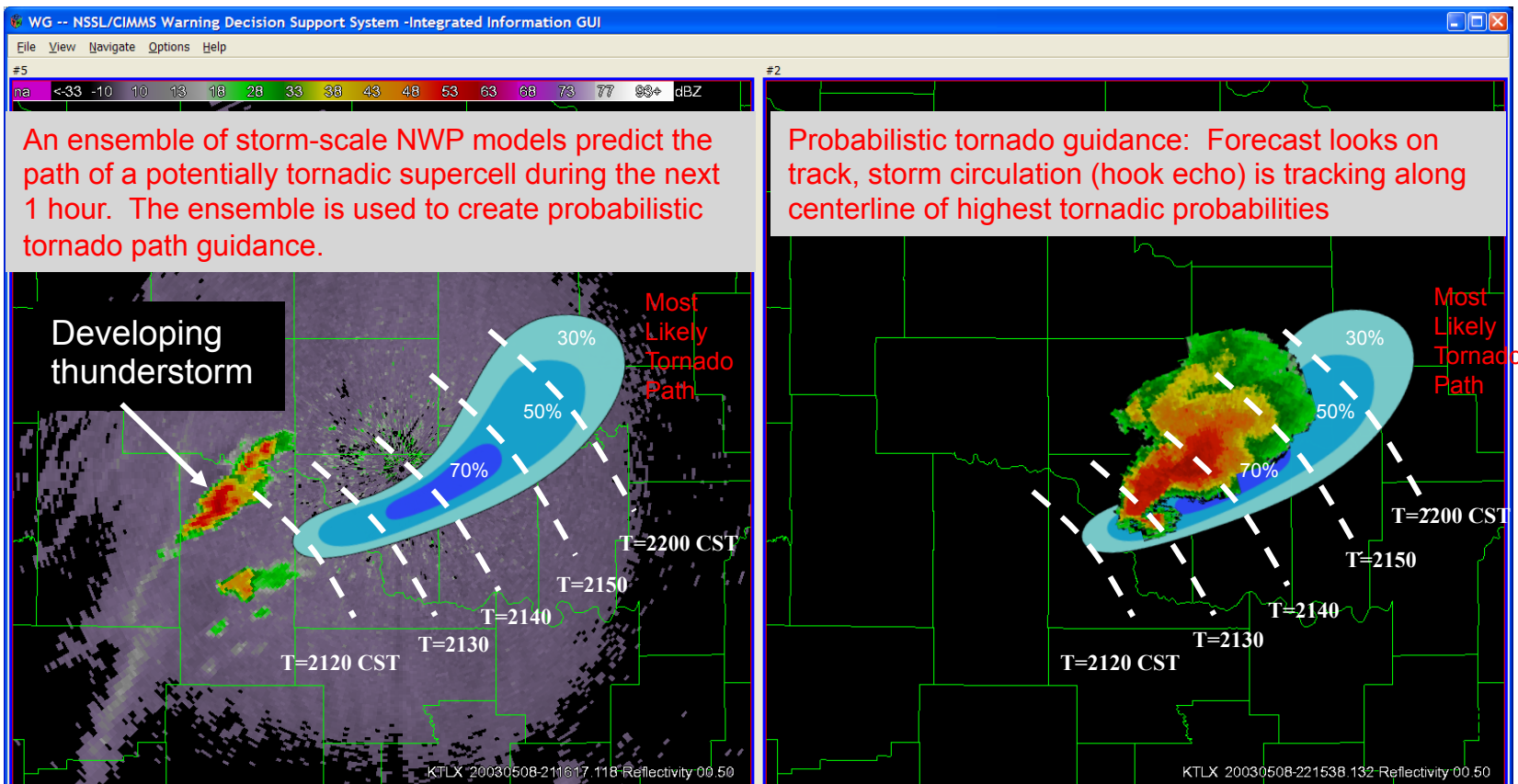
Warn-on-Forecast

- Key NWS Strategic Goal: extend warning lead times using ensembles of convection –allowing models (CAMs)
- A bridge between EFP and EWP activities as the distinction between forecasts and warnings diminishes
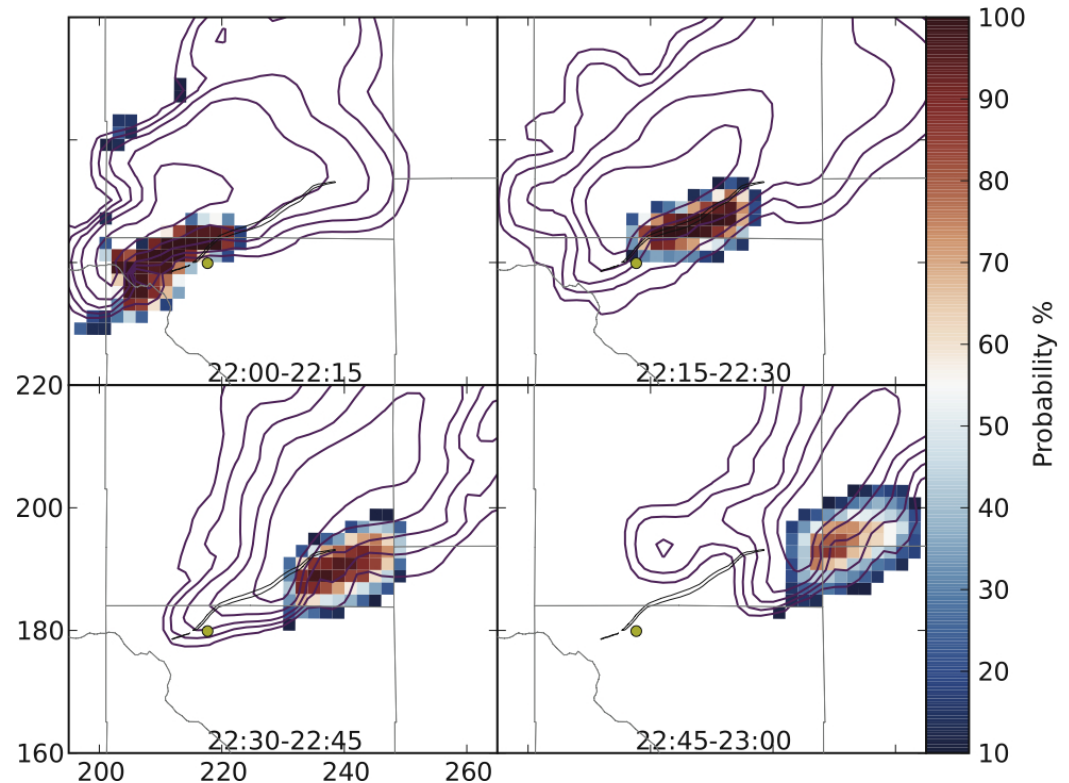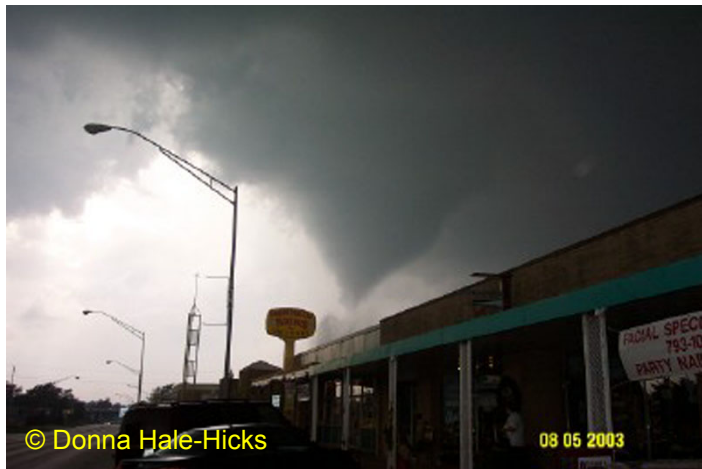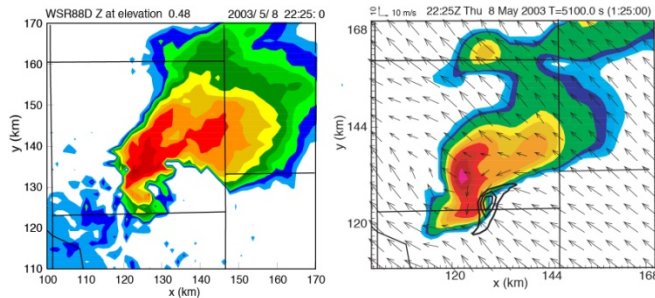
Warn-on-Forecast: 8 May 2003 OKC Tornado

Radar   Forecast

© Donna Hale-Hicks

Probability of strong low-level rotation over 15-minute forecast intervals derived from testing of a Warn-on-Forecast ensemble system. Note excellent comparison to observed tornado track (light black line).

HWT SFE 2012 Objectives

- **Spring Forecasting Experiment 2011: May 7 – June 15 (5 Weeks)**
- **Refocuses SFE activities on high priority topics for NSSL and SPC**

  - **Operational SPC Goal**
    - Develop, test, and evaluate the ability of ensemble systems (SSEF, SSEO, SREF) to **provide automated enhanced temporal resolution guidance** that would be applied to forecaster produced full-period (e.g. 24-hr) Convective Outlooks.
    - The full period forecaster created outlook defines the overall spatial PDF
    - Automated ensemble guidance to create a temporal PDF for the forecaster Outlook
    - Allows forecaster to focus on area of expertise (spatial PDF)

  - **Research NSSL Goal**
    - Investigate the utility of CAMs and ensemble systems in providing numerical guidance for hazardous convective weather
    - Focus on the **timing of initiation and transition processes** (changes in coverage and porosity, convective mode and intensity, and upscale growth)
    - Compare new algorithms for identifying CI events that utilize object-based tracking methods and warping/filtering strategies to optimize performance
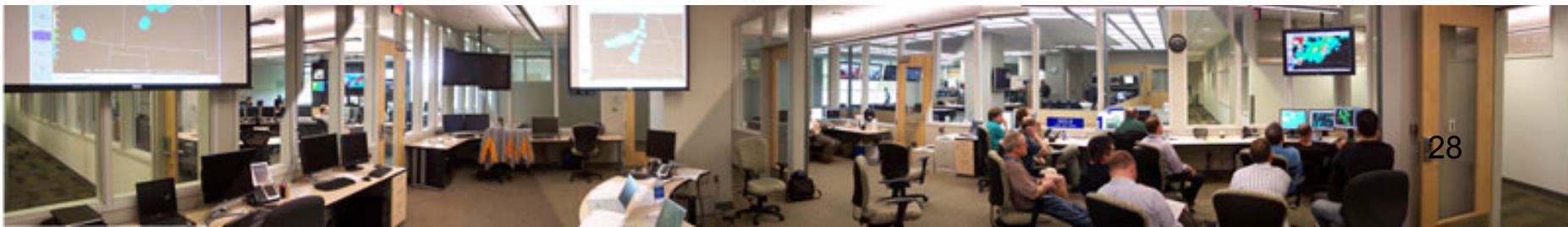
NOAA Hazardous Weather Testbed

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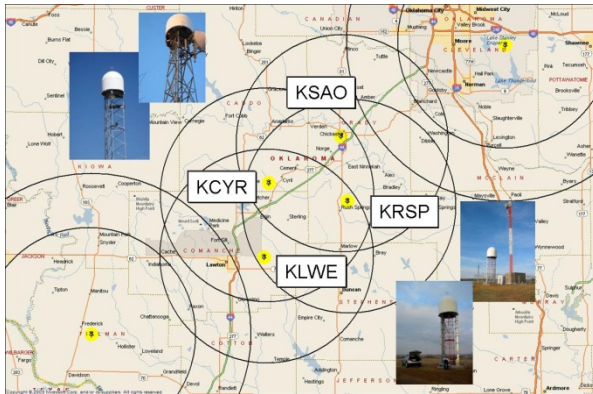## Three Main Program Areas…

Experimental **F**orecast **P**rogram

*Prediction of hazardous weather events from **a few hours to a week in advance***

EFP

EWP
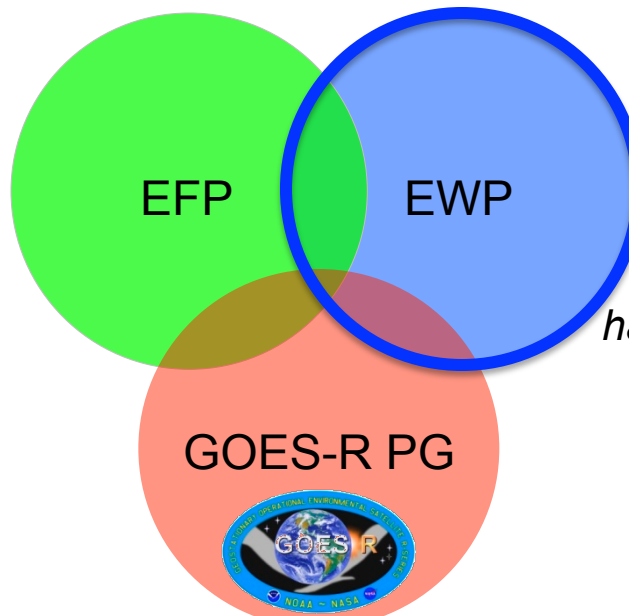
Experimental **W**arning **P**rogram

*Detection and prediction of hazardous weather events **up to several hours in advance***

GOES-R PG

GOES-R Proving Ground

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Broad Collaboration National scope

2010: **Phased Array**
Innovative Sensing
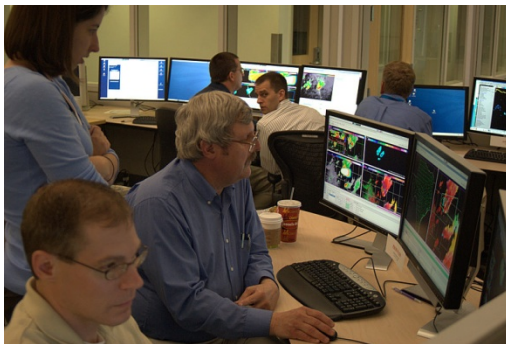Experiment (PARISE)

NWS forecasters (all regions)

NOAA researchers (NSSL, GSD)
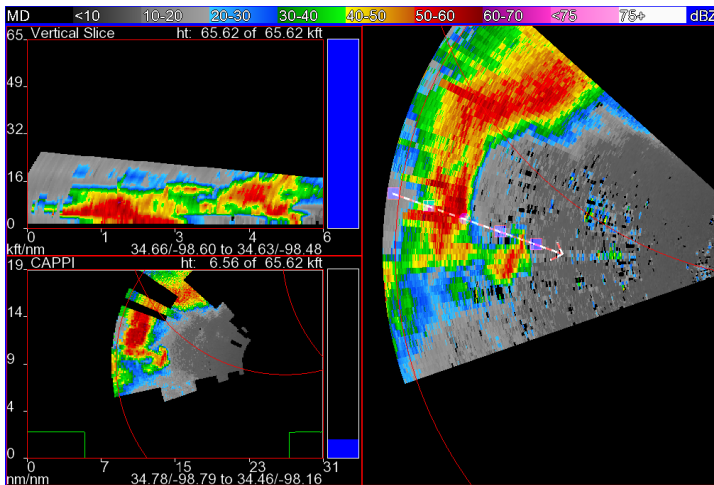
Multiple University
collaborators

2010: Collaborative Adaptive
Sensing of the Atmosphere (**CASA**)
Experiment

Long-Range Surveillance

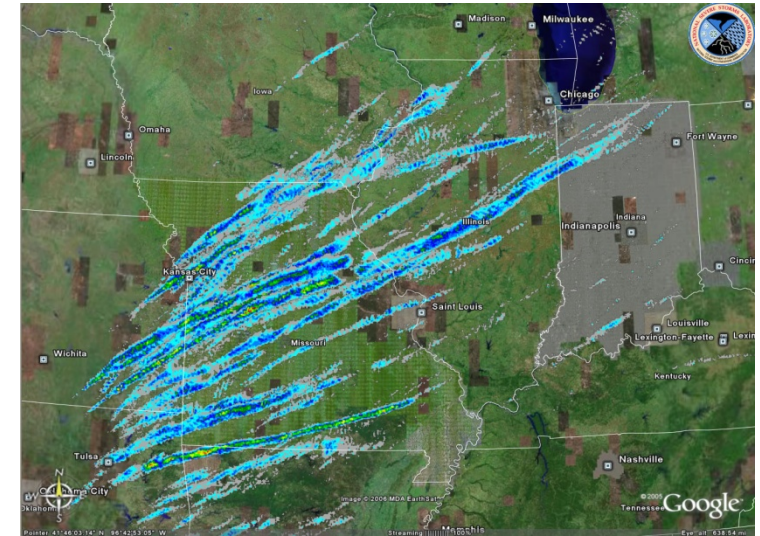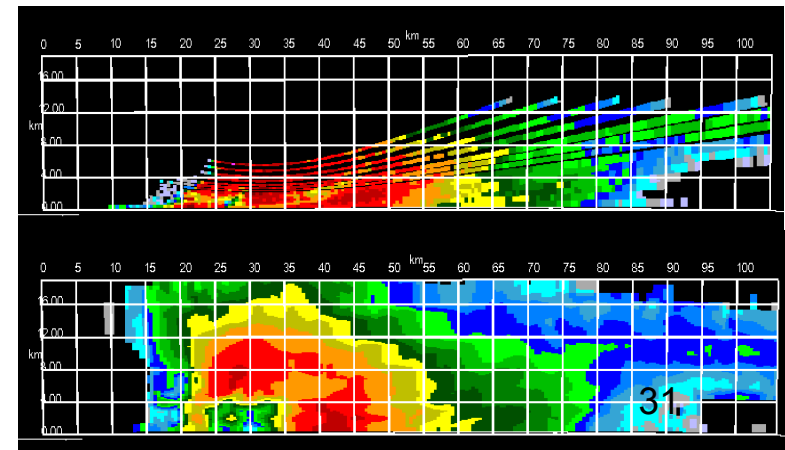Severe
Weather

Non-Cooperative
Targets

Weather
Fronts

WMD
Cloud

Terminal
Surveillance

30
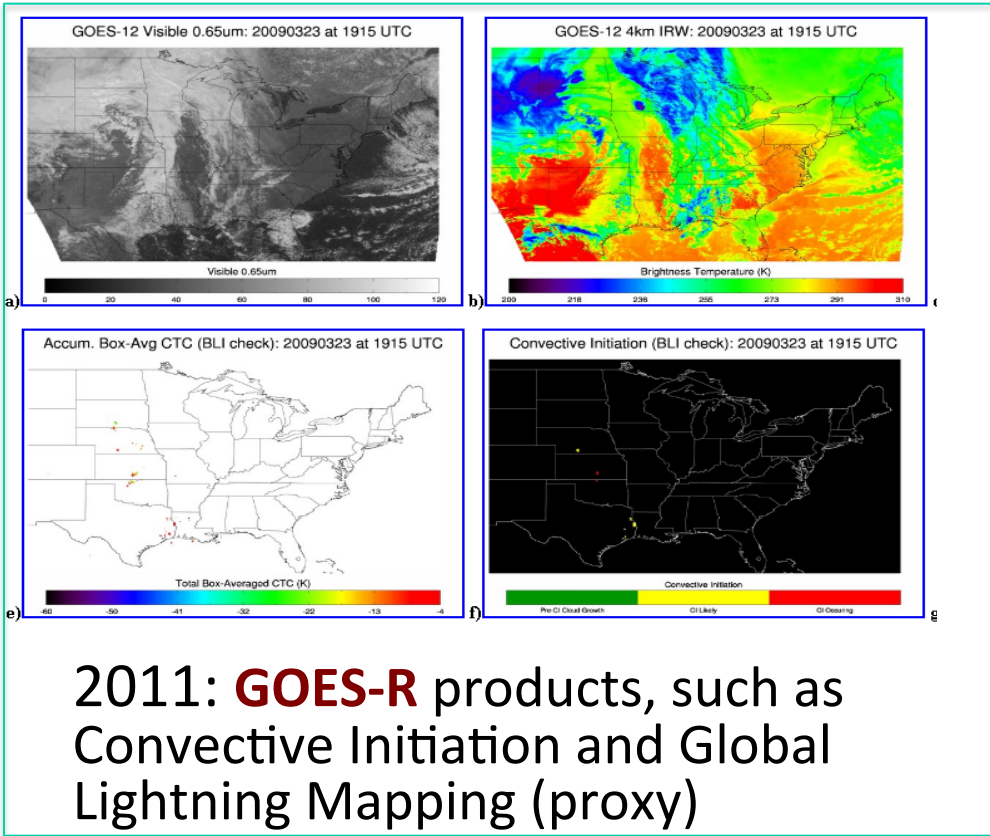
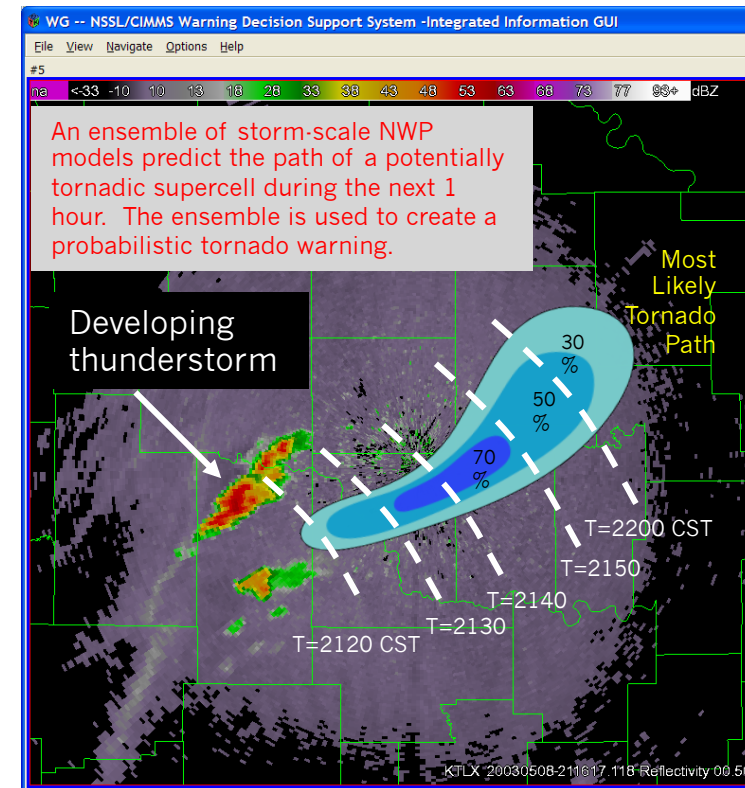2011: **GOES-R** products, such as Convective Initiation and Global Lightning Mapping (proxy)

2011: **Multi-radar / multi-sensor** products, such as 3D CONUS reflectivity, hail size estimates, "rotation tracks"

2011: **Warn-on-Forecast** real-time radar data assimilation

2012 EWP Spring Experiments

- May 7 – June 15, 2012

- AWIPS2-based for the 1st time

- Projects:

  - Warn-on-Forecast real-time 3DVAR data assimilation

  - OUN WRF local high-resolution modeling experiment

  - GOES-R product demonstrations for CI and warning operations including GOES Lightning Mapper proxy products


An ensemble of storm-scale NWP models predict the path of a potentially tornadic supercell during the next 1 hour. The ensemble is used to create a probabilistic tornado warning.

Most Likely Tornado Path

Developing thunderstorm

30%
50%
70%

T=2200 CST
T=2150
T=2140
T=2130
T=2120 CST

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2012 EWP Offline Activities

- PARISE 2012 (to include cognitive psychologists and educators with forecasters, plus expansion to include null cases and many more events)

- Lightning Jump Algorithm initial testing (1 Mar – 30 Oct)

- SHAVE (Severe Hazards Analysis and Verification Experiment) for testing experimental winter dual-pol hydrometeor classification algorithm

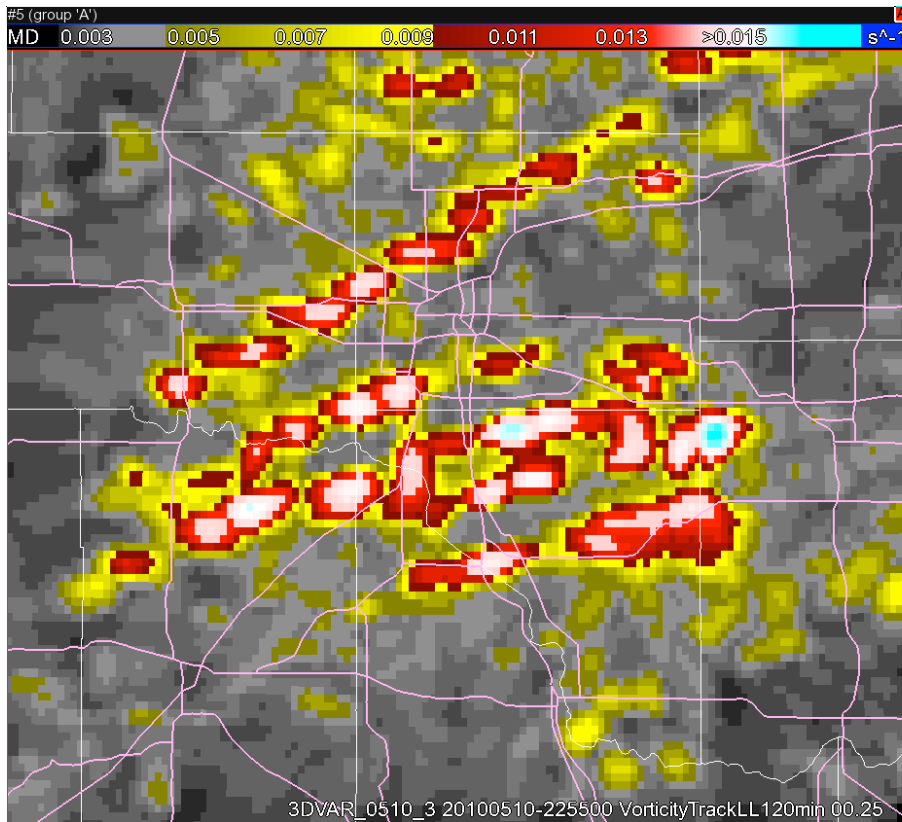- SHAVE for testing lightning jump algorithm relationship to hail and wind reports

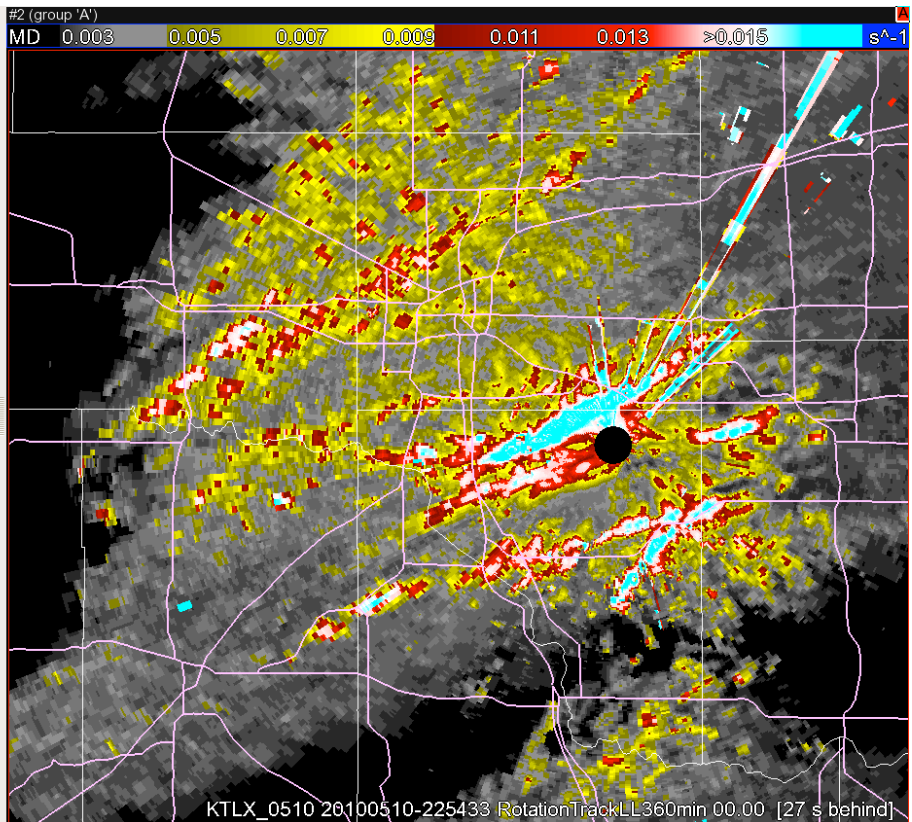# Warn-on-Forecast real-time 3DVAR data assimilation

Courtesy Lou Wicker
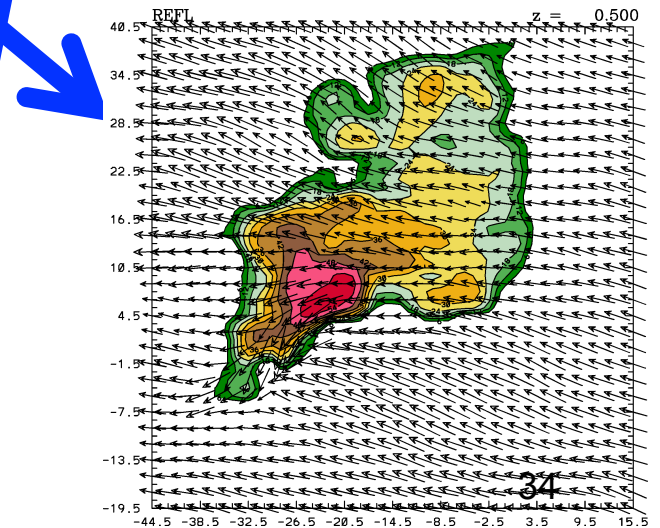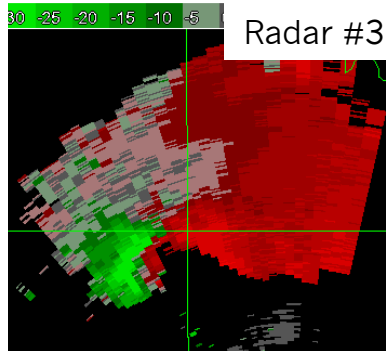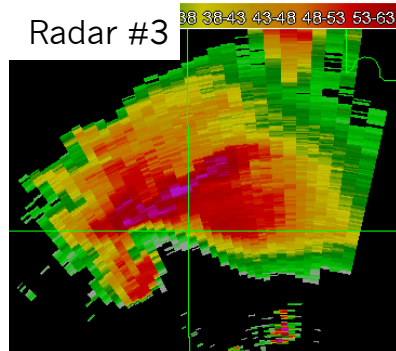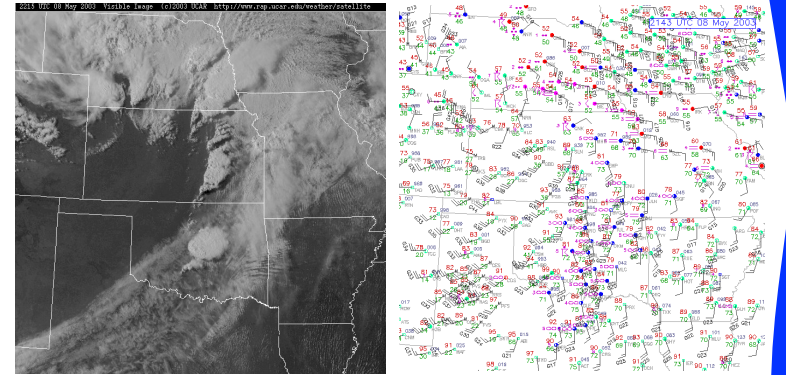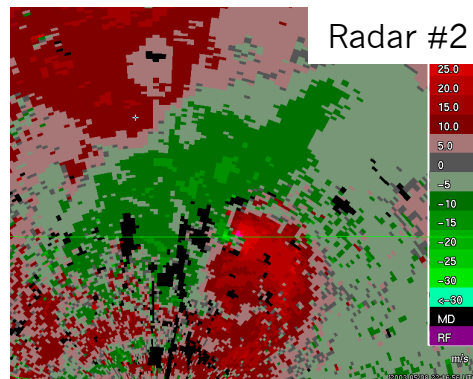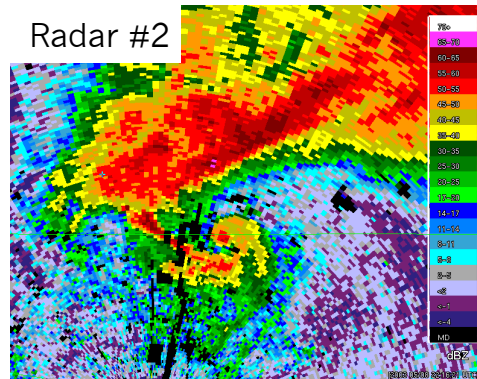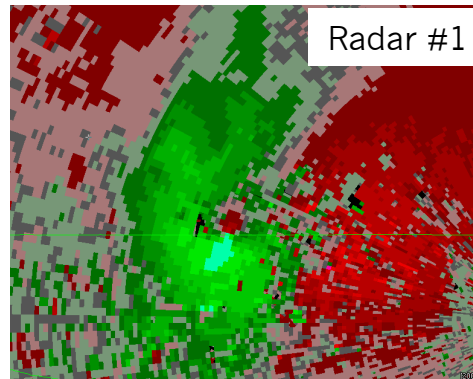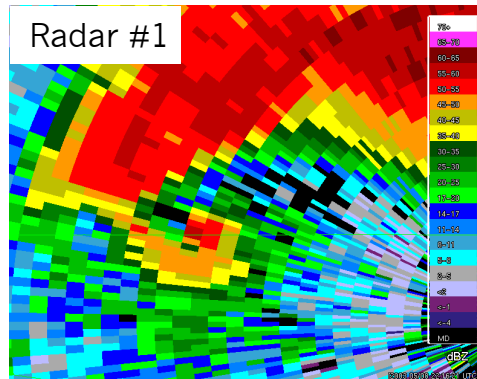
Case Example of 3DVAR:
May 10, 2010 OK Tornado Outbreak

Courtesy NWS-Norman
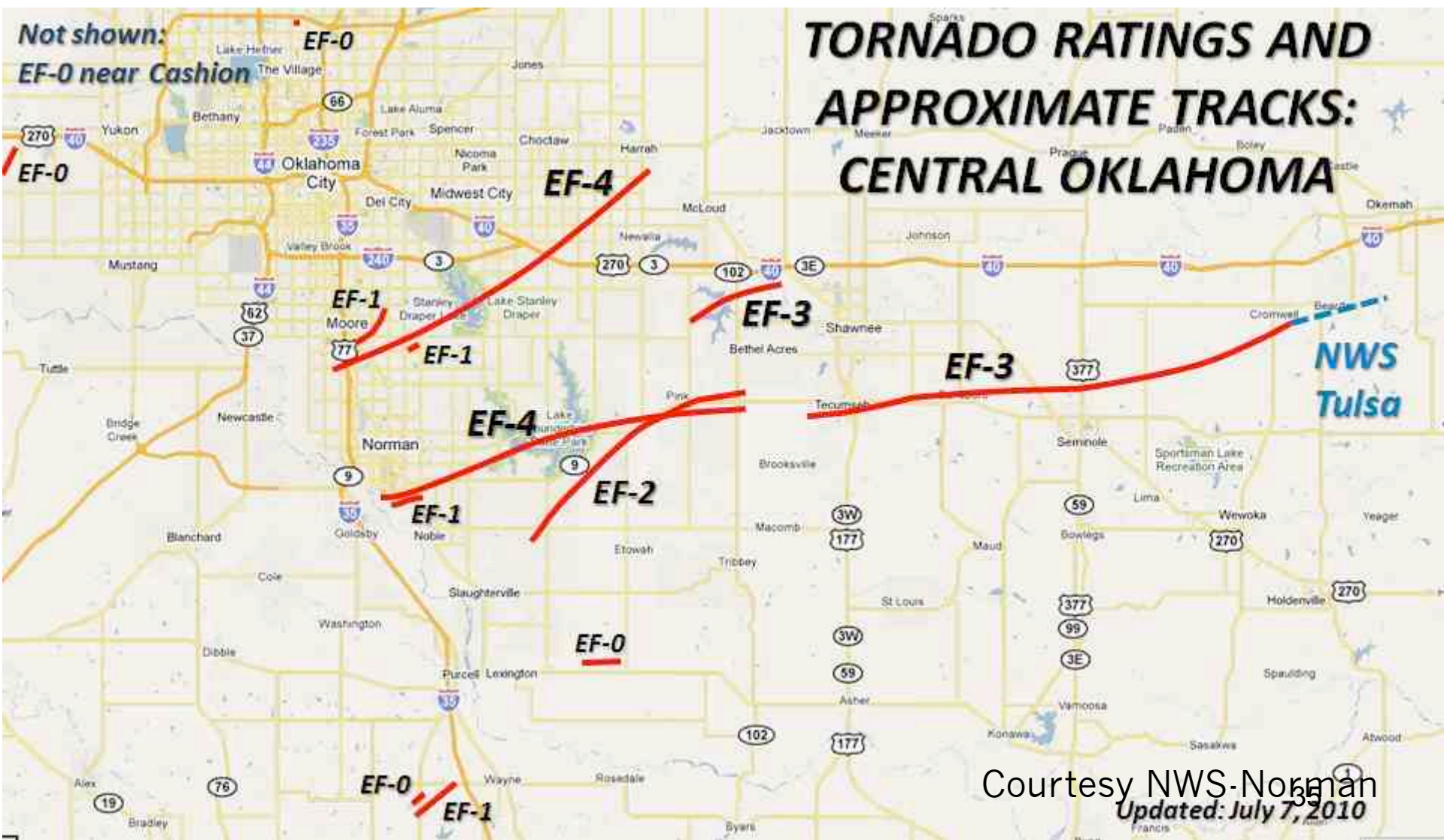
Case Example of 3DVAR:
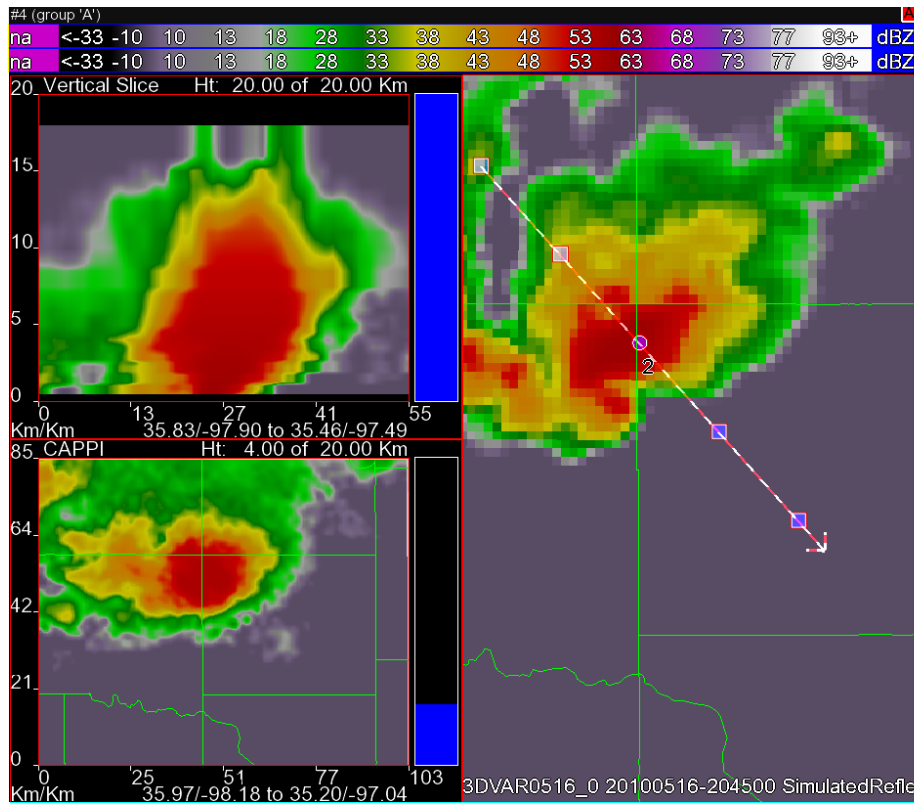# May 10, 2010 OK Tornado Outbreak

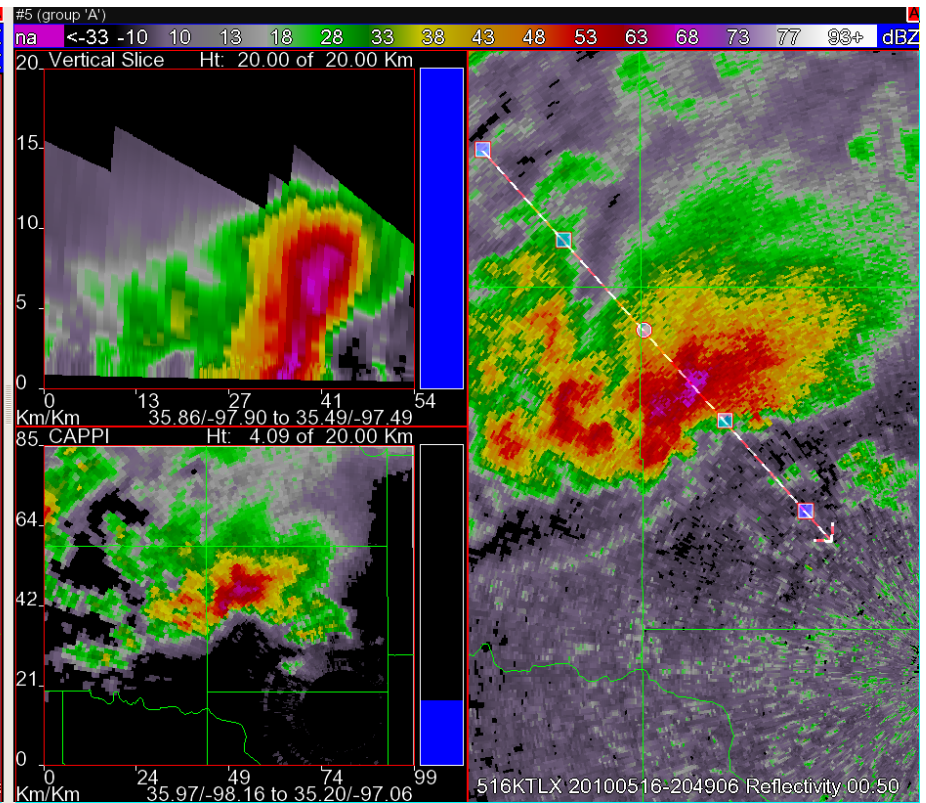3DVAR assimilation vorticity track
0-3 km MSL

KTLX azimuthal shear track
0-3 km MSL

Case Example of 3DVAR:
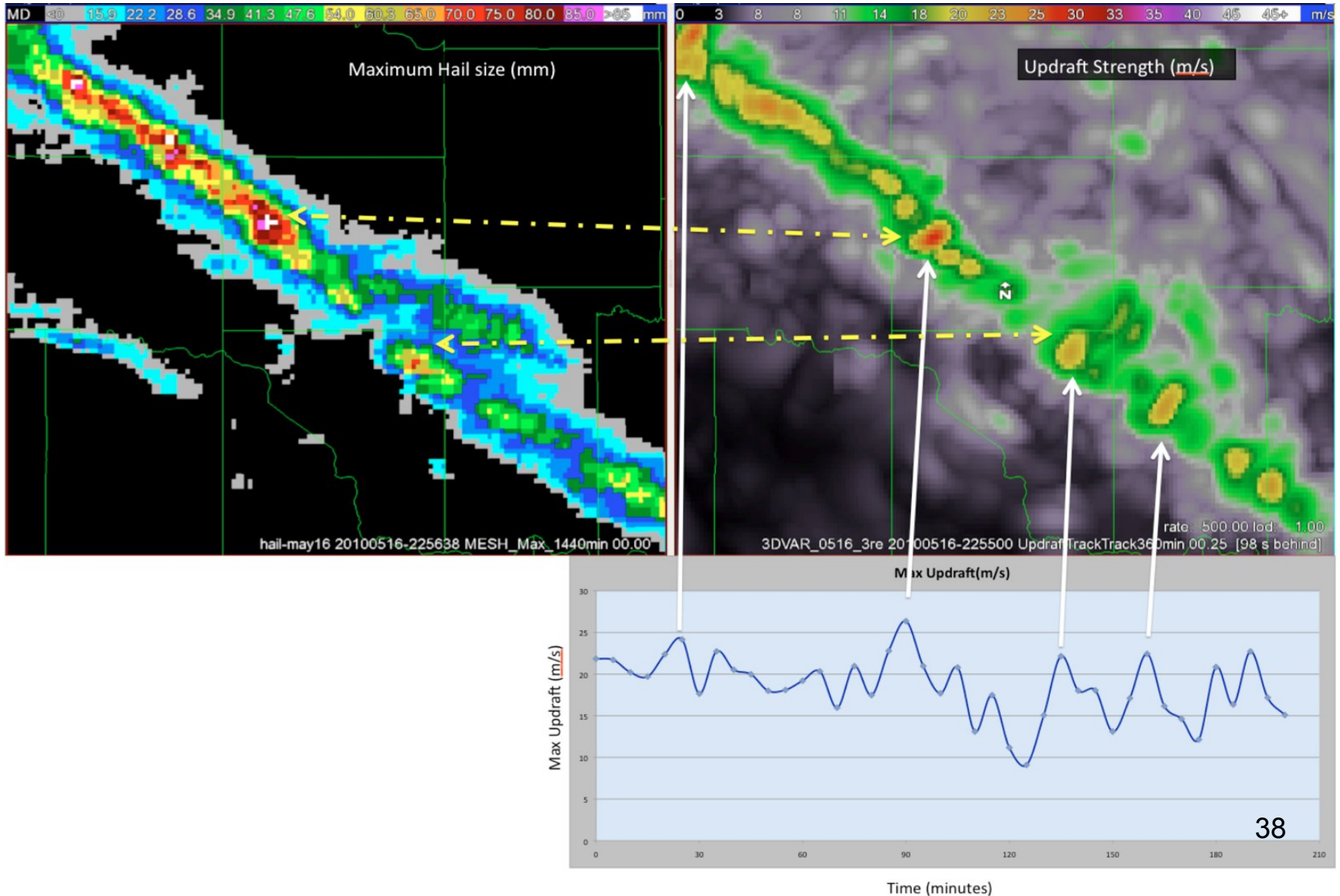## May 16, 2010 OKC Hailstorm

Assimilation simulated reflectivity

KTLX Reflectivity

May 16, 2010 Hail Size (MRMS) vs. 3DVAR updraft intensity

Norman Weather Forecast Office Local High-Resolution Modeling

Run every hour out to 8 hours at 3 km grid-spacing on a ~1300 x 1300 km domain centered on OUN.

In the AWIPS-II environment, HWT forecasters to examine:

Convective Initiation (CI)

> How well does the OUN WRF forecast the timing and location of CI?
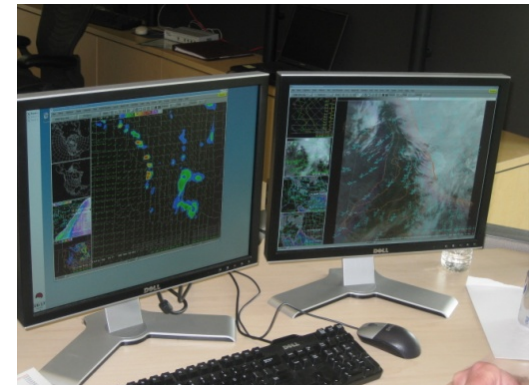
Convective Mode
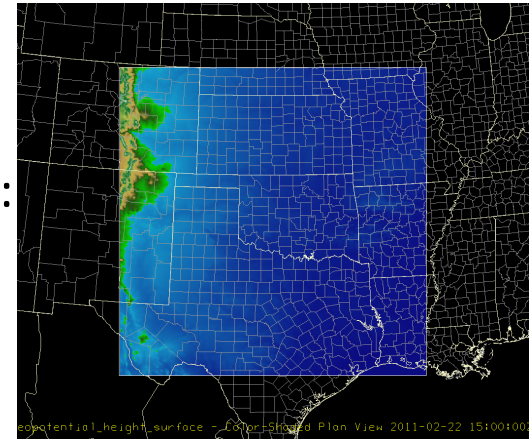
> How well does the OUN WRF forecast storm mode?

Storm Proxies

> Updraft helicity, composite reflectivity from the OUN WRF

Model Sensitivities

> How does the forecast change when varying the method of data assimilation? (LAPS vs. ADAS)

Probabilistic Hazard Information (PHI) "Threats In Motion"

- Warning automatically translates downstream based on the variation in past motion vectors, so when the storm turns or changes speed, the swath changes.

- Provides meaningful information about times of arrival and departure. Increases confidence.

- Locations where threat has passed, warning automatically removed.

- Can issue hazard grids at probability values *below* expected thresholds for issuing today's warnings.

  – Provide greater lead time to high risk users

  – Provide low-threshold information to users with higher-than-average vulnerability

- Future: blend statistical storm motion behavior with NWP ensemble model guidance
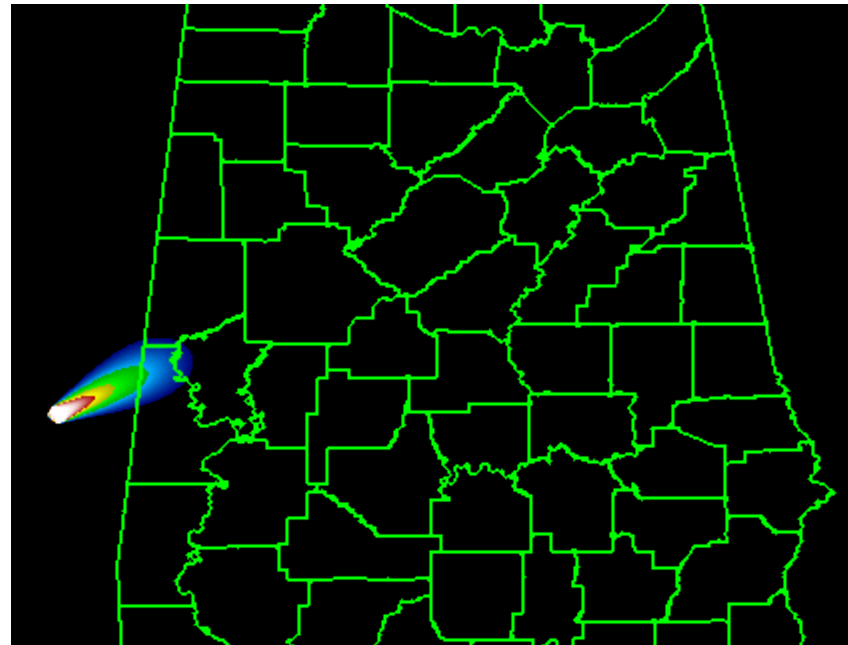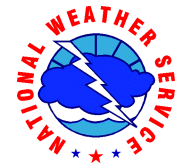

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NOAA Hazardous Weather Testbed

Supports and promotes collaborative research activities between SPC, NSSL, WFO OUN, and the broader meteorological community of research scientists, academia, and forecasters to accelerate the transition of promising new severe weather forecasting and warning techniques into operations.

Three Main Program Areas…

Experimental
Forecast
Program

Experimental
Warning
Program

EFP   EWP
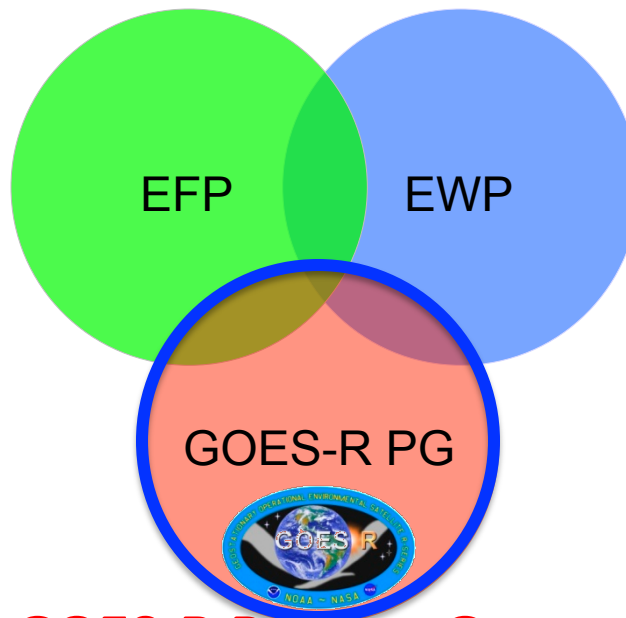
GOES-R PG

GOES-R Proving Ground

What is the GOES-R Proving Ground?

- Collaborative effort between NESDIS supported Cooperative Institutes, NOAA testbeds, NCEP National Centers, NWS

- Responsible for user readiness testing of GOES-R baseline/option-2 products prior to launch
  - Develop training for users
  - Prepare for display within AWIPS/AWIPS-II/N-AWIPS

- Provide feedback to product developers on experimental day-2 satellite products

2011 GOES-R Proving Ground Activities

- Continuing demonstrations
  - Convective initiation using cloud-top cooling rates
  - Overshooting tops / Enhanced-V detection
  - Pseudo-Geostationary Lightning Mapper (PGLM) total lightning detection
  - NSSL-WRF simulated GOES-R satellite imagery / lightning threat
- New products demonstrated
  - 0-6 hour Nearcast Θ_e/PW difference
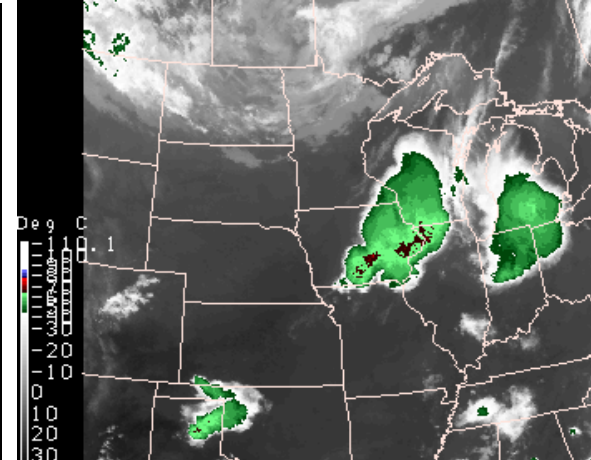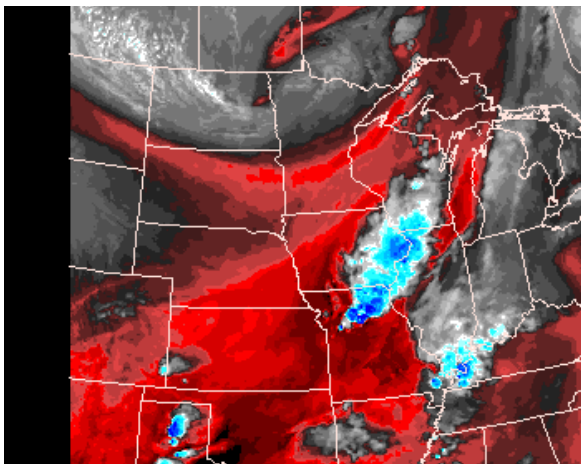 - NSSL-WRF simulated GOES-R band differences
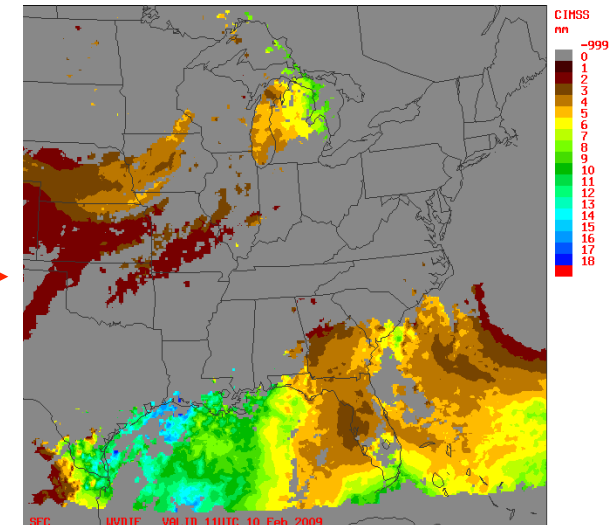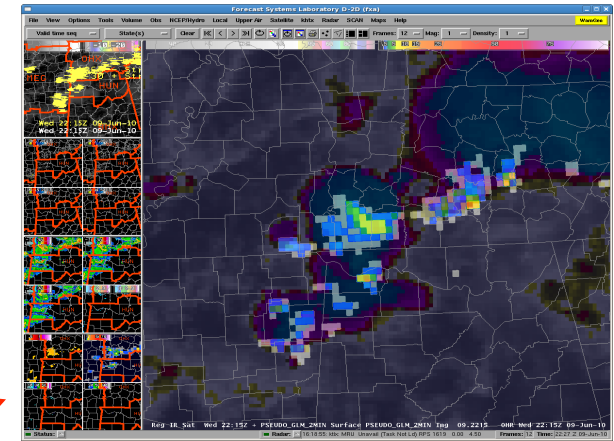
Collaboration with UW-CIMSS and CSU-CIRA scientists to generate synthetic satellite imagery from high resolution model forecasts
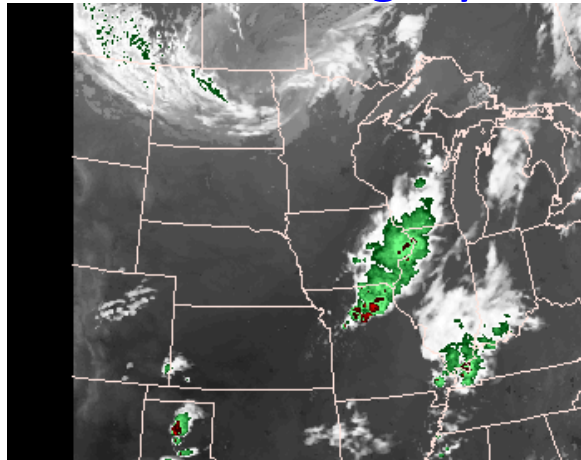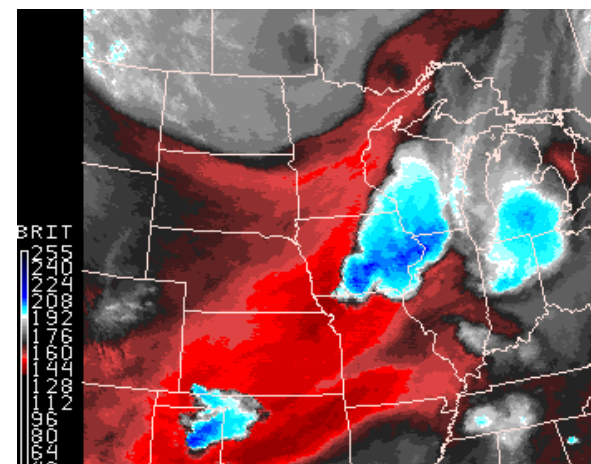

Model Forecast

Observations

Model Forecast

Observations

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Alpha testing in realtime 4 km NSSL-WRF forecasts: Lightning identification algorithm (McCaul et al. 2008)

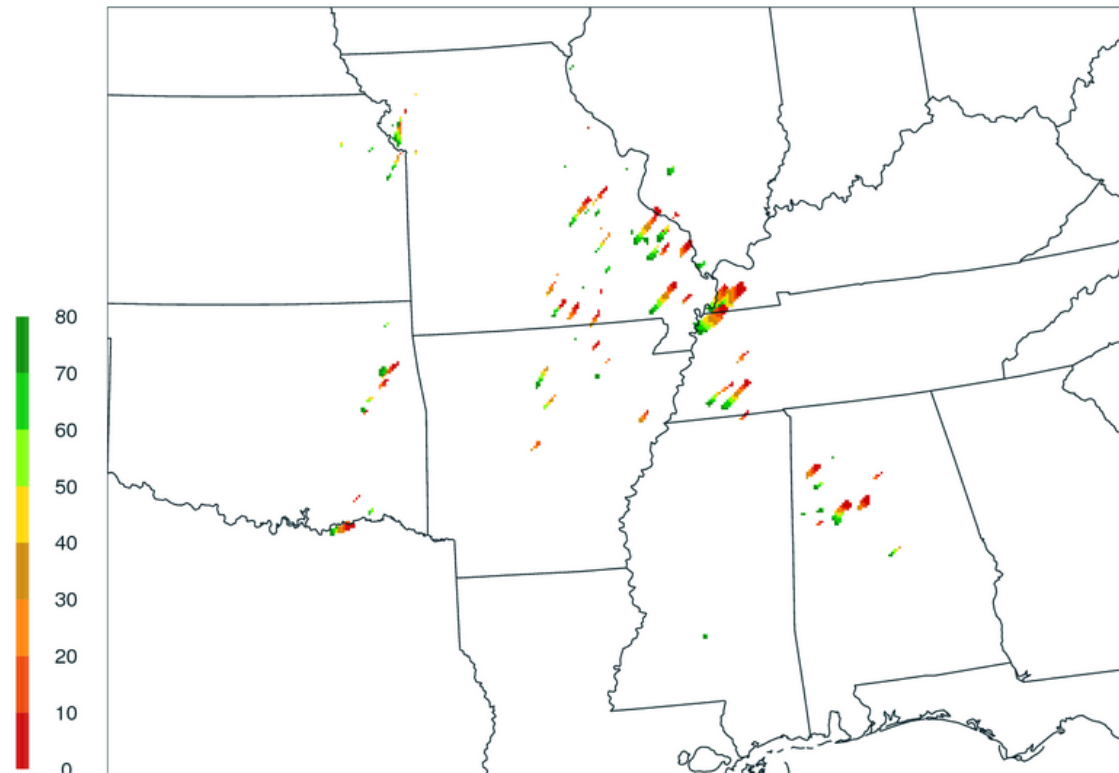# Alpha testing in realtime 4 km NSSL-WRF forecasts: Lightning observed by NLDN (McCaul et al. 2008)
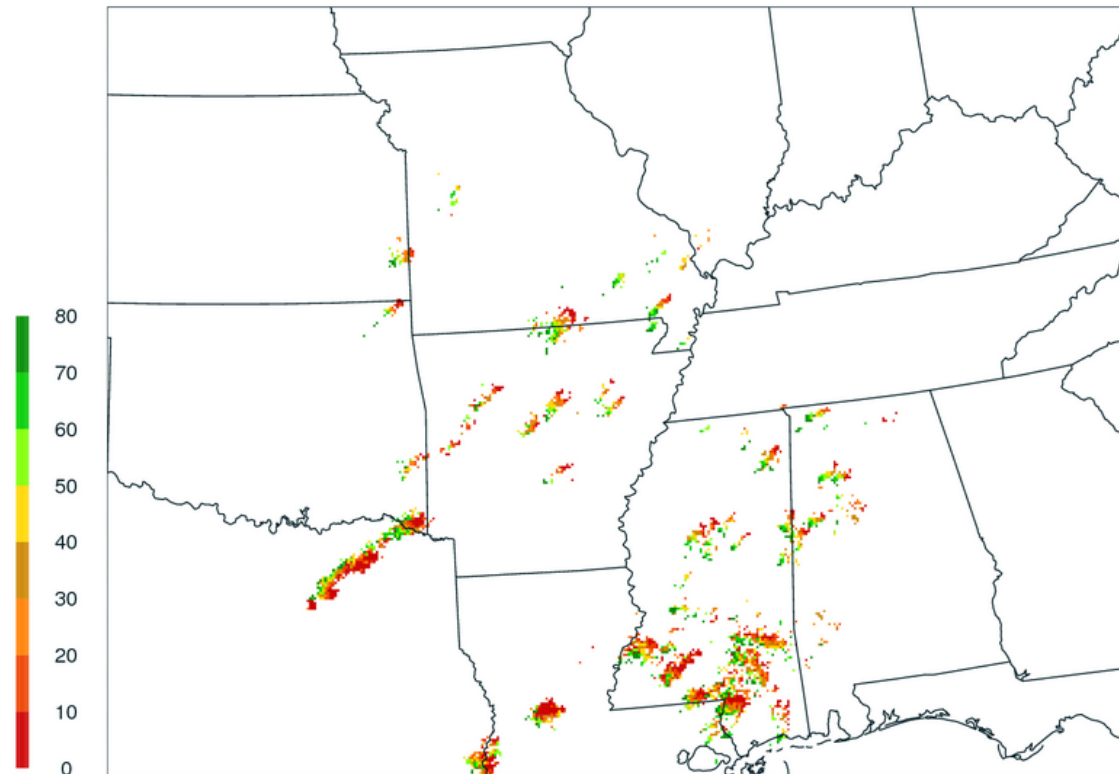
Future Program Areas for the Hazardous Weather Testbed

Intense Precipitation & Flash Flooding

IPFF

SS
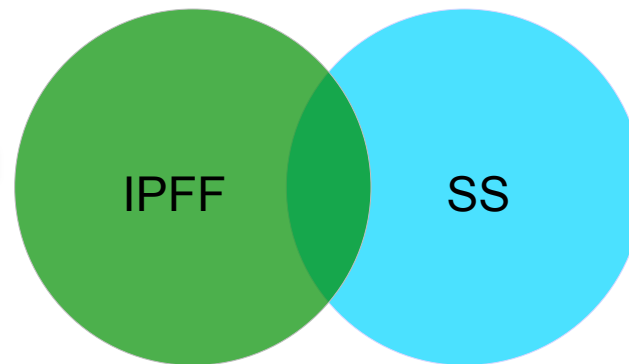
Social Science Integrated into HWT

Intense Precipitation & Flash Flooding (IPFF)

• Proposed supplement to HWT to build on the success of the existing QPF component and interactions with HMT-HPC

• Move from solely PQPF to a basin-specific Probabilistic Flash Flood Forecasting (PFFF) system – thus, a "super ensemble" system

• Experiment would be conducted after the 2013 Spring Experiment to avoid conflicts for resources and overstressing personnel, recognizing that warm season heavy precipitation is most prevalent in summer

• Goal is to transition new capabilities to operations at HPC

Social Science Integrated into HWT

- Study the manner in which forecasting teams utilize and process severe weather data

- Address the end-to-end forecast process from science to warning preparation and dissemination

- Understand how future fire hose of data will force changes in how forecasters can effectively perform their jobs

- Study the most effective ways for using social media for validation of severe weather and warnings dissemination

- PARISE 2012: Explore whether improvements in depiction of storm development from rapid Phased-Array Radar sampling may benefit forecasters' decision making process by relieving uncertainty and/or providing needed information when traditional-scan radar data is found insufficient for tornado warning decision making

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Weather Decision Training Branch

- Previous participation in HWT as coordinators, weather briefers, and participants since 2007, also key to transitioning products to AWIPS and AWIPS-2

- 2012 Goal: to capture what forecasters are doing during HWT and to regularly document experiences in a more public way

- Weekly 20-minute Webinar presentation given by the participants to those who sponsor HWT efforts and other interested folks.

Summary: Keys to Success

- A core group of individuals with complementary skills and a shared passion for operationally relevant research

- Close proximity and frequent interactions between researchers and forecasters

- A facility that enables experimental activities to occur

- Willingness among the core individuals to carry projects to fruition: co-authored journal publications, forecaster training modules, and technology infusion into operational improvements